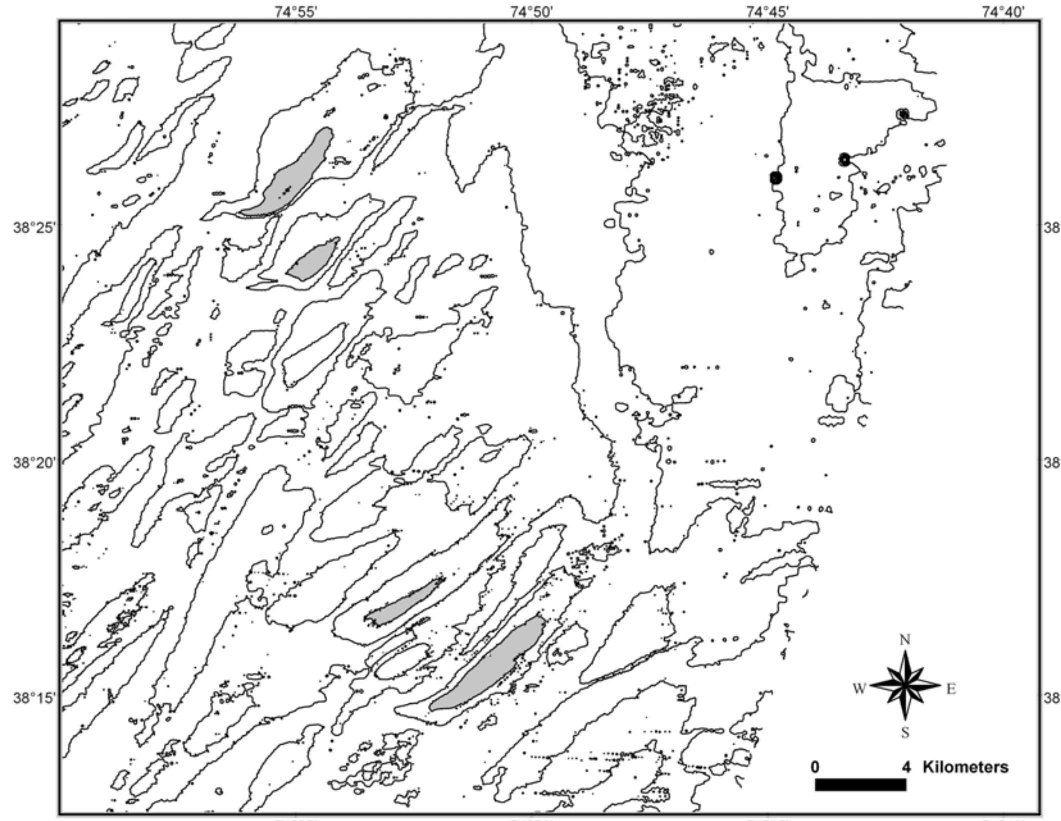
OCS Study
MMS 2005-042

FINAL REPORT

COMPARISONS BETWEEN MARINE COMMUNITIES RESIDING ON SAND SHOALS AND UNIFORM-BOTTOM SUBSTRATES IN THE MID-ATLANTIC BIGHT



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COMPARISONS BETWEEN MARINE COMMUNITIES RESIDING ON SANDSHOALS AND UNIFORM-BOTTOM SUBSTRATES IN THE MID-ATLANTIC BIGHT

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EXECUTIVE SUMMARY

Many of the beaches along the Mid Atlantic Bight (MAB) are undergoing long-term erosion due to sea level rise, human activities, and from severe coastal storms. In efforts to try to restore beaches lost to erosion various state and federal governmental agencies have ongoing or proposed beach stabilization projects that require significant sand resources to complete. As the need to replenish beaches increases new sand resources will be required and those will likely be taken or "mined" from federal waters. The Minerals Management Service (MMS) has jurisdiction over all mineral resources occurring in federal waters. The MMS along with both Maryland and Delaware Geological Survey have identified four specific sand shoals off of their coasts as potential resources for long-term sand mining. The specific shoals are, Shoal B, Shoal D, Fenwick Island Shoal, and Weaver Shoal. If shoals provide important habitat to specific marine communities, then mining activities could have negative impacts to those communities, and before mining can occur, information must be gathered pertaining to what species of fish and mobile benthos may be affected by mining.

The study was located on the inner continental shelf of the MAB region off the coast of Maryland and Delaware. The primary focus was the four sand shoals and four reference sites. The shoal and reference areas were located between 16 and 25 km off the coast and encompass approximately 800 square km of the inner shelf. The main objectives of this study were to, 1) determine what species of fish and mobile benthos reside at offshore sand shoals, and 2) evaluate if the shoals represent important habitat for those species. The focus of this study was to compare the four sand shoals to four reference habitats located in the same region that exhibited similar macro and microhabitat features, but did not exhibit vertical relief like the shoals. In this region of the MAB, shoals and uniform-bottom (lacking extreme vertical relief) habitats are the dominant megafeature. For comparison, four uniform-bottom habitats were chosen as the reference sites. To evaluate if shoals are important habitat, we compared species abundances and diversity between the four shoals and four reference habitats. Species abundance and diversity were used as determinants of habitat quality and we defined an area to be "preferred" if total species or communities occur at greater abundances and higher diversities within that area.

To identify comparable reference sites, underwater video technology was used to characterize the shoal and reference habitats. Reference sites were chosen based on similarities of physical and biological micro and macrohabitat features that were present at those sites and the shoals. Once the reference sites were identified, a multi-year comprehensive fisheries study consisting of daytime trawling, gillnetting and nighttime bioacoustics was employed to compare and contrast the abundance, diversities and distribution of fish and mobile benthos communities between the shoals and reference habitats.

Comparisons between shoals and reference sites for each season and gear showed mixed results with generally higher numbers of total species abundance, species richness, and species diversity at the reference sites in the trawl data and no clear patterns in gillnet data. There were significant seasonal differences in species densities throughout the study at all the sampling sites and between all gears. There were also differences in catch between all gears within a season. Analysis of specific species guilds showed that more benthic finfish, pelagic finfish, and pelagic invertebrates (squid) were captured in the commercial and small trawls at the reference sites compared to the shoals. In gillnets, all guilds except pelagic invertebrates were captured in about equal numbers, and no significant differences were detected. No pelagic invertebrates were captured in gillnets. In general, fish densities and biomass quantified using bioacoustics fluctuated between sites throughout the seasonal surveys. However, differences between individual shoals and their reference sites were found in many seasons and some patterns were evident within site pairs. In particular, Fenwick Island Shoal and Weaver Shoal exhibited higher nighttime densities and biomass when compared to their reference pairs, and when tests were significant they favored higher estimates at these shoals the majority of the time. Shoal B and D and their reference sites did not exhibit any consistent nighttime pattern of higher estimates throughout the study.

Two consecutive years of fisheries monitoring in Federal waters off the coast of Maryland and Delaware documented that there are significant seasonal variations in species richness and abundances at the shoals and reference sites in this region of the MAB. There were also yearly variations in abundance, but overall the seasonal patterns of species assemblages are consistent and the majority of the species inhabiting the shoals and reference site habitats are seasonal residents. Comparisons between the net and bioacoustic data suggest that pelagic fish are using habitats differently between day and night. Multiple analyses were conducted on the data collected over the two years and from those analyses we conclude that, 1) fish and squid occurring in the MAB either have no preference or prefer substrates at uniform-bottom types to sandy shoals during the day, 2) benthic invertebrates have no preferences for shoals over uniform-bottom types during the day, and 3) there are diel (Day/Night) differences in the abundance of pelagic fish using the shoals and reference sites. Theses data suggest fish could be using the adjacent uniform-bottom habitats during the day and move onto the shoals at night to exploit new habitat, in which case shoals could represent an important resource for fish at night.

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1.0 INTRODUCTION

Coastal and marine tourism is one of the largest industries in the world, and is the largest growing industry in America (Miller 1993). In particular, beaches represent the biggest attraction for coastal tourists with an estimated 180 million Americans making 2 billion trips to the beach annually (Houston 1996). Beaches have an intrinsic value that is appreciated by all citizens, yet they also generate economic wealth from year to year for local and national governments, households and businesses. For example, in Monroe County Florida, yearly visitors spend about $1.12 billion dollars accounting for nearly 50% of all income and employment in the county (English et al. 1996). In addition to providing public recreation, beaches also function as protection from storm winds and waves, thereby reducing losses of infrastructure and private property to coastal communities in extreme weather. Thus, a great deal of effort has been spent trying to stabilize and maintain beaches along our coasts.

Galgano (1998) estimates that between 85 and 90% of the beaches along the East Coast are undergoing long-term erosion due to sea level rise, human activities, and from severe coastal storms. In efforts to try to restore beaches lost to erosion several management strategies have been employed with minimal success (Green 2002). One common and effective management strategy has been beach nourishment. This process involves the placement of sand fill, with or without supporting structures, along the shoreline to widen a beach. Sand is usually dredged from offshore sand deposits or “borrow” sites and pumped or taken directly to a beach by a dredge. Beach nourishment is the only management tool that serves a dual purpose of protecting coastal lands and preserving beach resources.

Beach nourishment projects have been conducted since the 1950’s and currently several states along the Middle Atlantic Bight (MAB) have either ongoing or anticipated beach nourishment projects. To guarantee the sustainability of nourished beaches, several states have developed long-term beach maintenance plans that include routine beach nourishment projects. For long-term management to be successful, access to beach quality sand is imperative, and therefore, as near-shore sand resources are depleted, efforts to identify new long-term sand resources are moving farther offshore onto the continental shelf region of the Exclusive Economic Zone (EEZ) (3 to 200 nautical miles from shore; see Drucker et al. 2004 for a more detailed description).

Under the federal Outer Continental Shelf Lands Act (P.L. 103-426), all mineral resources within the EEZ, including sand, gravel, and shell, falls under the jurisdiction of the Minerals Management Service (MMS). To ensure the availability of suitable sand for future beach nourishment projects, the MMS in collaboration with several coastal state agencies have been conducting detailed geologic investigations of continental shelf mineral resources (Drucker et al. 2004; Michel 2004). Investigations off the coast of Maryland and Delaware by the State Geological Survey have identified numerous shoal fields as potential sites with suitable sand for beach nourishment (Conkwright and Williams 1996; Conkwright et al. 2000). Within these shoal fields several individual shoals have been designated as potential resources for long-term erosion and emergency damage control on local beaches.

The MMS is obligated to comply with all relevant federal, state and local policies and regulations in planning and implementing any sand mining in federal waters under their jurisdiction. As stewards of these resources the MMS must ensure any use of sand resources does not adversely affect marine biological resources. MMS's "Environmental Report: Use of Federal Offshore Sand Resources for Beach and Coastal Restoration in New Jersey, Maryland, Delaware, and Virginia" (MMS 1999) was prepared to assist MMS in meeting those regulatory obligations, in particular the requirements of the National Environmental Policy Act (NEPA). In addition to meeting NEPA requirements, MMS must also coordinate with the National Marine Fisheries Service (NMFS) in order to comply with requirements of the Magnuson-Stevens Act with regard to protection of Essential Fish Habitat (EFH).

A review of the Environmental Report suggests that while extensive geological investigations have been performed to assess the quantity and suitability of the shoal sands as beach nourishment material (e.g., Conkwright and Gast 1994), the ecological value of the shoals and their importance to the marine biota have been subject to only limited study. In particular, the value of individual shoals as EFH has not been specifically addressed, and little information is available relative to the use of specific shoal areas by fish and various mobile species.

Unlike tropical and Pacific marine habitats adjacent to the continental United States, the inner continental shelf of the MAB is relatively flat and devoid of hard natural structures, such as reefs (Stiemle and Zetlin 2000). Most of the shelf is composed of soft sediments, mostly sands, but grading to silt-clay in deeper areas. Sand shoals are considered the dominant structure providing vertical relief in an otherwise flat environment (MMS 1999; Stiemle and Zetlin 2000).

Vertical relief in the bottom profile can be of enhanced value as forage and refuge areas for marine fish and benthos species (Kohn 1967; Gilinsky 1984; Diaz et al. 2003). The majority of information pertaining to marine communities and vertical relief comes from studies of natural and artificial reef fish communities (Brock 1954; Sale 1991; Williams 1990; Rilov and Benayahu 2000). Combined with diverse spatial heterogeneity, it has been shown that vertical relief directly influences reef fish community structure, fish density, and dictates the presence or absence of certain species (Sale et al. 1994). On the west coast, high relief associated with rocky reefs increases densities of rockfish and is likely to be one of the most significant environmental determinants of distribution, abundance, and species richness (Larson 1980; Richards 1986; Williams 1990; Yoklavich et. al. 2000). In their assessment of the Gulf of Mexico ancient reefs, "the pinnacles", Snyder (2001) found a higher abundance of fish species at high relief areas when compared to low relief, but noted that habitat complexity was more of a factor influencing distribution than was relief alone.

Most of the work along the east coast regarding marine species communities has focused on the mesoscale distribution (Grosslein and Azarovitz 1982; Colvocoresses and Musick 1984, Musick et al. 1986; Murawski 1993) and environmental preferences of fishes (Stiemle and Zetlin

2000; Colvocoresses and Musick 1984). Some information exists describing fish assemblage in relation to habitat, however, these studies either focus on deep continental shelf communities (Auster et al. 1995; Langton et al. 1996; Auster et al. 2001), or are directed toward the understanding of species-specific life stages (Bologna 2002; Diaz et al. 2003; Miller et al. 2003). Rarely have studies addressed the relevance of specific habitats to communities as a whole within the inner continental shelf of the MAB, and little information exists relative to the use of offshore shoals by fish or mobile benthos.

EFH is defined broadly under the Magnuson-Stevens Act as “those waters and substrate necessary to fish for spawning, breeding, feeding and growth to maturity.” Current EFH for fish species in New England and the Middle Atlantic Bight is derived using abundance data from broad fishery-independent trawl surveys (Reid et al. 1999) rather than specific habitat criteria. Because most managed species are widely distributed, this approach designates EFH for most species at the megahabitat scale (i.e., the continental shelf). While assigning large areas as EFH is protective of a species, it does not contribute to the identification and conservation of specific habitats, such as shoals, which may be important to a species at the meso or macrohabitat level (Slacum et al. 2005).

Further, provisions of the act require a more holistic approach in managing marine fish stocks (Benaka 1999). This requirement necessitates evaluating the effects of potential disturbances at the community scale and not just for single species under management. To thoroughly evaluate impacts to marine communities, an attempt to identify and describe the biota of an area both spatially and temporally must be done. In addition, because there are considerable similarities in community structure defined by ecological associations, classifying communities into functional groups or guilds can also be used to gain better insight into the function of a specific habitat (Joern and Lawlor 1990; Auster 2001; Aguilar-Ibarra 2003). Subsequently, the number and abundance of ecologically functional guilds present in particular habitat can be used in determining if that habitat is unique as compared to other surrounding habitats. If the habitat is determined to be unique, then decisions can be made regarding the influence that particular habitat may have on the ecosystem as a whole. Knowledge of such information is critical when there is potential for negative impacts; however, under the current state of knowledge the ecological value of shoals and their importance to specific marine biota cannot be effectively determined.

1.1 PROJECT OVERVIEW AND OBJECTIVES

The MMS in collaboration with both the Maryland and Delaware Geological Survey have identified four specific sand shoals off of their coasts as potential resources for long-term sand mining. The specific shoals are, Shoal B, Shoal D, Fenwick Island Shoal, and Weaver Shoal. If shoals provide important habitat to specific marine communities then mining activities could have negative impacts to those communities. Therefore, the MMS funded the current study to design and implement a field program to address the following two objectives: 1) determine what species of fish and mobile benthos reside at offshore sand shoals, and 2) evaluate if the shoals represent important habitat for those species.

In the ocean, habitats occur at many scales and are generally defined by their geology, biology, and physical climate. Four generally accepted categories of marine habitat are mega, meso, macro, and microhabitats (Greene 1999). Shoals are a megahabitat features (< kilometer) comprised of macro and microhabitats. Mesohabitats are those features having a size of tens of meters to a kilometer. Macrohabitats are features such as sand waves, boulders, and bars, and microhabitats are fine scale features like biogenic structures, sand, or other seafloor material (Greene 1999). The focus of this study was to compare the four sand shoals to four reference habitats located in the same region that exhibited similar macro and microhabitat features, but did not exhibit vertical relief like the shoals. In this region of the MAB, shoals and uniform-bottom (lacking extreme vertical relief) habitats are the dominant megafeature (MMS 1999). For comparison, four uniform-bottom habitats were chosen as the reference sites. Because species abundance and diversity have long been recognized as indicators of community structure, with higher abundance and diversities indicating more complex and stable ecosystems (May 1975), in this study, we use those measures as determinants of habitat quality and define a habitat to be "preferred" if total species or communities occur at greater abundances and higher diversities within that habitat. In order to identify comparable reference sites and to quantify species and community abundance three specific methods were used.

Those methods were:

1. Use remote video technology to identify and characterize reference locations in proximity to the shoals that exhibited uniform bathymetry (i.e., non-shoal), but that are otherwise nearly identical to the shoals in terms of micro and macrohabitat features;
2. Conduct a multi-year comprehensive fisheries study to compare and contrast the abundance, diversities and distribution of fish and mobile benthos communities between the shoals and reference habitats; and
3. Use bioacoustics to map fish relative biomass, densities and distributions at the shoals and at reference habitats.

To accomplish the project objectives, Versar, Inc. compiled a multidisciplinary team of experts, including several University scientists as sub-contractors. Figure 1-1 shows the project team and responsibilities of each team member. The project organization included oversight of all project tasks by Versar, Inc. with specific tasks managed by appropriate experts. The qualifications and responsibilities of all primary team members are listed below.

William Burton - Versar, Inc.: Program Manager/Senior Scientist

- Over 20 years of experience designing and implementing fisheries and benthic ecological monitoring programs and impact assessments

- Authored or co-authored more than 150 reports and peer-reviewed publications
- Single point of contact with MMS project management staff, and final editor and contributing author to final project report and manuscript

H. Ward Slacum Jr. - Versar, Inc.: Project Manager/Fisheries Ecologist

- 15 years of professional experience designing, managing, and conducting aquatic surveys and biological assessments in the Mid-Atlantic Bight Region
- Extensive experience defining and evaluating aquatic habitats as they relate to aquatic natural resources
- Project manager responsible for supervision of all staff, including subcontractors, directed data analysis and was primary author of the final report

Bob Diaz - VIMS: Lead Benthic Habitat Characterization/Benthic Ecologist

- Senior Benthic ecologist with over three decades of research experience
- Extensive experience conducting remote sensing sediment and benthic community characterizations along the east coast using underwater videography
- Technical lead for habitat characterization, responsible for video sled data acquisition and analysis, and reference site selection

Kyle Hartman - WVU: Lead Bioacoustics Survey/Fisheries Biologist

- Extensive publication record in the use of bioacoustics in fisheries surveys, with many projects having been conducted in support of the U.S. Corps of Engineers
- Technical lead for the bioacoustics survey, responsible for collecting and analysis of bioacoustic survey data

Roberto Llansó - Versar, Inc.: Multivariate Statistics/Benthic Ecologist

- Over 10 years experience in conducting ecological and sediment quality assessments, and developing metrics for benthic indices
- Contributing author for the Multivariate Analysis Section

Ed Weber - Versar, Inc.: Multivariate Statistics/Senior Statistician

- Nine years of research experience in fisheries ecology and management, statistical analysis, population-dynamics modeling, and technical writing
- Contributing author for the Multivariate Analysis Section

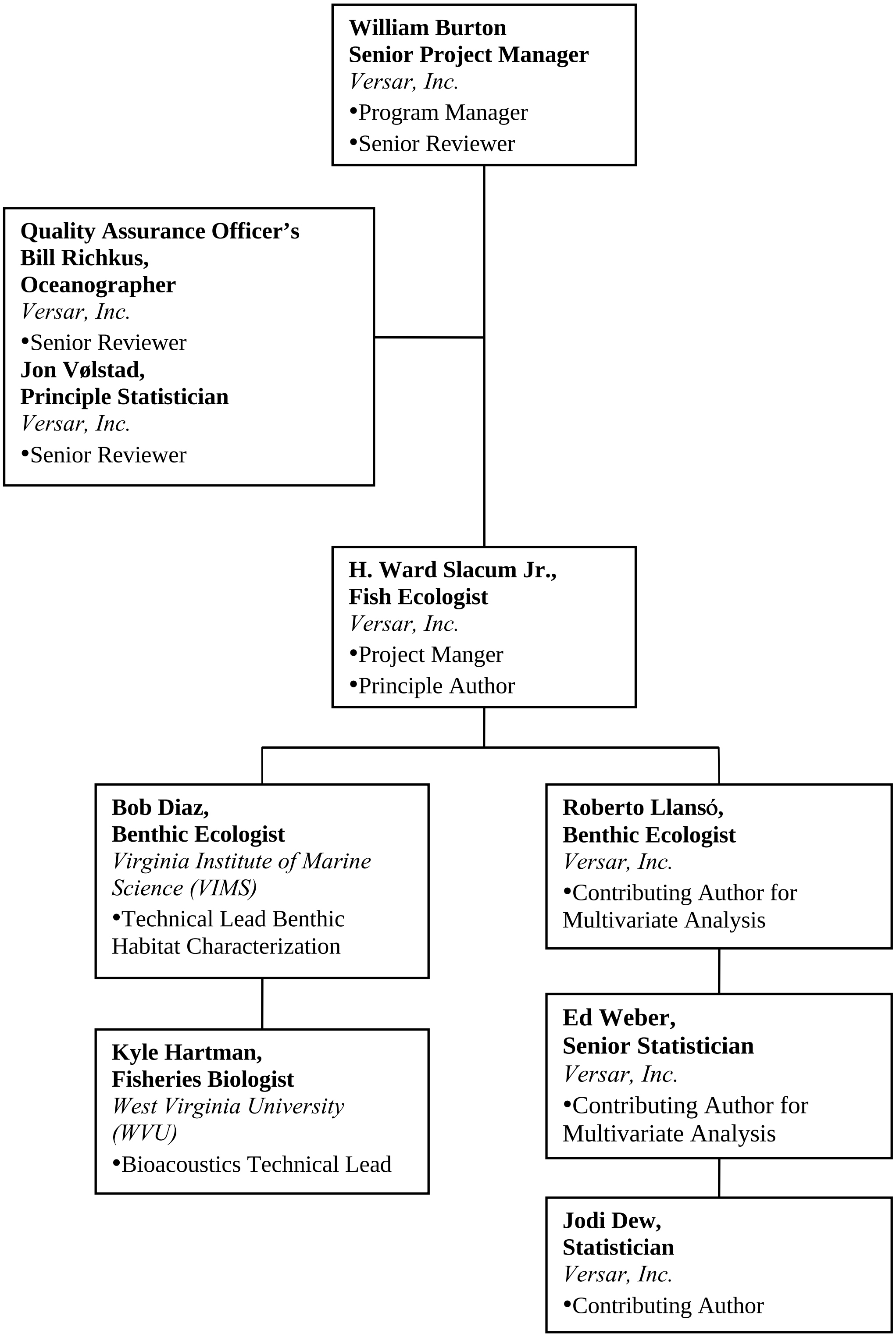


Figure 1-1. Project organization chart and responsibilities.

1.2 ENVIRONMENTAL SETTING

1.2.1 Climate

The weather in the study area is characterized by extreme climate variability. Weather conditions in the fall and winter consistently produce strong storms with extreme winds and high seas. Summer conditions are much more stable with the prevailing southerly winds rarely reaching 20 knots during the day. Prevailing winds in the fall and winter tend to be out of the northwest, but occasional nor’easters occur. These storms can last for several days and generate high winds, cold rain, and heavy seas (MMS 1999).

The dominant water mass in the study area is from coastal inputs and adjacent shelf waters. Other water masses occurring over the continental shelf are the slope, and the Gulf Stream water masses. Water over the shelf originates from the coastal waters of Canada where is moves southward down the coast over the shelf. Currents over the shelf generally move in a southerly direction, however, patterns can change depending on wind conditions, local tides, and influences from other water masses. Shelf water is continually modified from coastal influences and air-sea interactions, and because of this, the shelf water mass can experience large temperature and salinity fluctuations. Temperatures range from a low of 3.0ºC in winter to nearly 26ºC at its maximum from late summer into fall. Salinities are generally highest around the coast in the winter when coastal riverine influence is less, and lower salinities occur in late spring to early summer (MMS 1999; Hardaway 2000).

Waves over the inner continental shelf are primarily derived from air-sea interactions generated from far offshore. Although local wind conditions can influence wave action within the study area, air-sea interactions created by two semi-permanent pressure systems are what influence the dominant wave patterns in the area. Southwesterly winds with average winds of three m/sec are generated in mid-summer by the Bermuda High, and in the winter months three to five m/sec west to northwesterly winds are generated by the Icelandic Low pressure system (MMS 1999). Subsequently, there are strong seasonal fluctuations in wave heights over the inner shelf. Waves approach the study area from the northeast to southeast directions, but waves from the east and southeast are more common (Hardaway 2000). Average waves in the area were recorded with heights 0.8 m and periods of 8.2 seconds. Waves generated by storms can be 2.7 m in height with a period of 11 seconds on average (MMS 1999).

1.2.2 Biological Resources

The biological resources that occur in the study area along the inner continental shelf region of the MAB are unique. This region of the inner shelf is comprised of a large variety of species with varying temporal and spatial patterns. Nowhere else in the Atlantic do such a wide variety of cold-temperature, warm-temperature, and estuarine species co-exist. Seasonal changes in water temperature are primarily responsible for species composition and distribution, but sediment type, water depth, and hydrodynamics are also important (MMS 1999).

Phytoplankton, zooplankton, and ichthyoplankton resources in the study area are very abundant. Phytoplankton has been estimated to have the highest productivity along the east coast (Sherman et al. 1996). Coccolithophores and silicoflagellates dominate production, but species of dinoflagellates and single celled diatoms are also abundant in the study area (Raymond 1963). There are approximately 400 taxa of zooplankton species in this area including copepods, cheatognaths, barnacles, cladocerans, appendicularia, brachyuran, echinoderm, and thaliaceans (Sherman 1996). Zooplankton biomass is at its peak in late summer after rising from low abundance in the winter months. Ichthyoplankton diversity and abundance is highly seasonal in the study area. However, Grosslein and Azarovitz (1982) noted large amounts of fish larvae can be found throughout the year.

Benthic resources in the study area consist of moderate densities of Arthropoda, Annelida, Mollusca, and Echinodermata (Wigley and Theroux 1981). Many of the benthic organisms located in the study area have wide ranging distributions within the entire MAB region. Benthic community found in the study area are similar to those off New Jersey, but biomass and species densities are lower than what is common in northern areas (Wigley and Theroux 1981). Common macro invertebrates include lobed moon snail, whelks, sea stars, surfclams, and horse shoe crabs (USACE 1998). Recent work done by Cutter and Diaz (2000) in the study area reported over 160 taxa benthic organisms from 72 samples. The most abundant species in that study were Annelid worms, followed by mollusks and crustaceans. Species densities ranged from 90 to 70,000 organisms/m^2 and biomass was from 0.03 to 2,000 g wet/m^2. These results are similar to those reported by Scott and Burton (2005) who surveyed several sites inshore from those reported by Cutter and Diaz (2000).

Nekton resources in the study area consist of fish, sea turtles, marine mammals, and large mobile invertebrates (squid). Most of the fish and squid, and all the sea turtles and marine mammals are seasonal migrants through the area (Musick et al. 1986). Resident species include few fish but several macrobenthos invertebrates are common throughout the year. Over 300 species of fish are known in the MAB and many of them occur within the study area on a seasonal basis (Sherman et al. 1996). Several recent inshore studies conducted in the area by Slacum et al. (2005) and Scott and Burton (2005) list over 60 fish, 16 invertebrate, and several squid species in the area. The highest diversity was found in the summer and the lowest diversities were found in the winter (Scott and Burton 2005).

Five species of sea turtles occur in the study area, of which the loggerhead and Kemp’s ridley are the most abundant. The leatherback, green, and hawksbill turtles also occur, but are far less abundant. Most turtles overwinter south of Cape Hatteras and migrate into or through the area in early spring or summer. Loggerhead turtles reach peak abundance in the study area during the summer (Keinath et al. 1987), and Kemp ridley are at peak abundance during fall migrations (Musick 2000).

Upward of 20 marine mammals, including pinnipeds and cetaceans, may occur in the study area on a seasonal basis (Waring et al. 2002). The study area is adjacent to areas on the mid-shelf, where marine mammals that prefer fish and squids are known to concentrate (Kenney and Winn 1986). In the summer, bottlenose dolphin occurs in high concentrations in the study area, and the boreal harbor porpoise dominates in winter (Waring et al. 2002). Harbor seals are also common in the study are during winter. Several whales are transient seasonally through the area. Juvenile humpback whales are known to overwinter in the area. Right whales are common in the area during migrations to and from calving grounds in the South Atlantic. Short-finned pilot whales are also common in the study area during summer months (Waring et al. 2002). See MMS (1999) for a detailed review of specific species occurring in the study area.

1.2.3 Geology

This part of the continental shelf is characterized by gentle slopes of 0.1°or less. Topographic and subsurface features on the shelf consist of paleoshorelines; shoals; filled channels; and retreat paths of estuary mouths (MMS 1999). Toscano et al. 1989 identified the stratigraphy of the inner shelf of Maryland and based on seismic records and sedimentological analyses, a late Quaternary stratigraphic model was developed. Five distinct stratigraphic units were identified and described on the Maryland inner shelf (Kerhrin et al. 1999). These units represent late Pleistocene interglacial deposits of transgressive shelf sands. Subsurface sediments are characterized by a Tertiary unit with steep internal reflectance and extensive channeling near its top. Overlying the Q1 unit, the Q2 unit is a 6-meter thick mud sequence of oxygen-isotope stage 5 (128-75 ka) age. Units Q3 and Q4 representing fluvial and leading edge estuarine deposits (oxygen-isotope stages 4, 3 and 2) filled numerous paleochannels that were incised into units Q2 and Q1. Modern trailing-edge transgressive shelf shoals (Unit Q5) discontinuously cap the sequence (Kerhrin et al. 1999).

Surface sediments off the Maryland and Delaware coasts within the study region are mostly terrigenous sand and silt with locally abundant clays. Muddy sands are located close to shore and in the troughs between linear shoals. Estuarine deposits consist of channel fill sequences with a prevalence of mud and peat with channel fill sand. Paleochannels fills that underlie linear shoals contain silty fine sands. Nearshore tidal fills consist of fine sands, dark grey mud, and interbedded sand and mud. Detailed geological descriptions of the Maryland inner shelf can be found in Toscano et al. (1989), Wells (1994), and MMS (1999).

1.2.4 Linear Shoals

The study shoals are part of a network of linear shoal fields, also referred to as ridge and swales, which constitute the majority of prominent natural features on the Delmarva inner shelf (Wells 1994). Linear shoals are scattered along the continental shelves, and have been observed in the central Dutch coast (Van de Meene 1994), along the German coast (Antia 1996), the middle Atlantic shelf of South America (Swift et al. 1978; Parker et al. 1982), and the east coast of Australia. Linear shoals are just one of several types of sand bodies present on the continental shelf of the USA, and the best examples occur in the MAB, northeastern Gulf of Mexico, and Sable Island Bank, eastern Canada (Michel et al. 2001).

Since Uchupi's (1968) description of their occurrence, numerous investigations have been conducted along the Atlantic inner continental shelf looking into the origins and morphological characteristics of linear sand shoals (e.g., Duane et al. 1972; Swift et al. 1972; Swift and Field 1981; Figueiredo et al. 1981; McBride and Moslow 1991), but still their origin is in question. Several researchers suggest the shoals were formed in response to nearshore storm generated currents and eventually become detached as a result of sea level rise (Duane et al. 1972; Field 1979; Swift and Field 1981). McBride and Moslow (1991) correlated the shore attached and detached shoals with historical and active tidal inlets. Still others suggest that they are maintained by the confluence of wave, tide, and oceanic currents (Hayes and Nairn 2004).

Once formed, shoals become detached from the adjacent shoreface as sea level rises and continue to evolve in form and size. As water depth increases, sand ridges increase in height, width and area, become more asymmetric, and exhibit lower contrast in grain size between up and down-current flanks with respect to the primary coastal flow distribution (e.g., Stubblefield and Swift 1976; Swift and Field 1981; Figueiredo et al. 1981; Snedden et al. 1999). Although there are numerous theories to what exact mechanisms are behind the formation and maintenance of these shoal features (Hayes and Nairn 2004), it is generally accepted that maintenance and evolution of shoal features changes from nearshore to offshore.

Several authors attribute the maintenance and evolution of shoal features by way of the dune-forming processes, where erosion from the up-current flank is deposited on the down-current flank (Stubblefield and Swift 1976; Rine et al. 1991; Snedden et al. 1999). Subsequent enlargement of the shoal in deeper water may be accomplished through the merging of smaller shoals and the addition of excavated underlying sands. In deep water, however, the processes of dune forming may not be as dramatic and shoals formation may become inactive due the armoring of the sediment surface, inhibiting erosion (Goeff et al. 1999). The evolution and maintenance of shoal features may be dependent upon the local sediment budget and associated sediment transport processes (Byrnes et al. 2004). However, because these processes are complex and difficult to study few attempts have been made to quantify the relationship between sediment transport and shoal maintenance (Hayes and Nairn 2004). Most of the work regarding shoal maintenance in deep water is related to effects of shoal manipulation on local wave processes and or borrow pit evolution (Byrnes et al. 1999; Byrnes et al. 2000).

Recently, Hayes and Nairn (2004) proposed a way of investigating shoal maintenance in wave dominated environments. Using a Boussinesq wave model (phase revolving) developed by the Danish Hydraulic Institute (Madsen et al. 1991), Hayes and Nairn (2004) evaluated the influence of waves on a two of the study shoals offshore of Maryland and Delaware. This model simulates irregular multi-directional waves including full and partial reflection, and current interactions. To evaluate waves influencing Fenwick shoal, a northeasterly storm wave was simulated that represented the dominant storm wave direction within the region. Results of that simulation indicated that waves would wrap around Fenwick shoal from the seaward end and converge at the crest near the landward side. In addition, this would be the active area of net sediment transport. These results indicate a mechanism for extending the shoal in the direction of the steep edge of the shoal, a phenomenon documented by other researchers.

Linear shoals are generally found in clusters with long axes that trend obliquely relative to the coastline and are oriented into the predominant storm wave direction (McBride and Moslow 1991). Along the MAB, linear shoals are located within the inner, mid, and outer continental shelf, and are generally similar in morphology and size. Shoals off the coasts of Maryland and Delaware range from 3 – 12-m in relief, 0.9 – 2.8-km in width, and are spaced 1.5 – 11.1-km from one another (Swift and Duane 1981). Vibracore records taken through the crest of some of these shoals show a large portion of the sands represent modern transgressive shoal sands, with sediment characteristics ranging from homogenous sands to stratified, alternating layers of sand, silt and clay (Wells 1994; Conkwright 2000).

2.0 FIELD METHODS

2.1 STUDY AREA

The study was conducted on the inner continental shelf of the Middle Atlantic Bight region off the coast of Maryland and Delaware, known as the Delmarva shelf. The primary focus was four sand shoals; Shoal B, D, Fenwick, and Weaver, and reference sites located in the same region. The shoal and reference areas were within and adjacent to several shoal fields that are located between 16 and 25-km off the coast and encompass approximately 800 square km of the inner shelf (Figure 2-1). The approximate latitude and longitude location of each shoal and the minimum and maximum sampling depths are presented in Table 2-1.

The four specific shoals identified as sand resources off the Maryland and Delaware coasts are located within 20-km of the shore, between the 10 and 20-m contour. Each of the study shoals share similar morphological characteristics associated with linear shoals, but all of them possess a unique shape and differ in their relief. The average base depth for all the shoals is 18.3-m deep, but Fenwick and Weaver exhibit shallower areas with minimum depths of 3.8 and 7.3-m compared to 8 and 11-m minimum depths found at shoal B and D, respectively. The shoals differ in their grade of relief with Fenwick Island Shoal and Weaver Shoal exhibiting slopes with over 30% grades and shoal B and D with less grading (Conkwright and Williams 1996; Conkwright et al. 2000).

The reference sites were of similar sizes as the study shoals and as indicated from underwater video footage (Nestlerode and Diaz 2003; Appendix A) the reference sites exhibited similar habitat characteristics to the shoals, but were generally much deeper than shoals. These sites were deeper and of uniform bathymetry and did not exhibit any significant relief like the shoals. Average sampling depths with approximate latitude and longitudes of the reference areas is presented in Table 2-1.

2.2 SAMPLING DESIGN

A randomized paired site design was used to compare the distribution, total relative abundance, and diversity of finfish and mobile benthos species residing on the shoals and reference sites. Four pairs of sites were established by pairing each of the four shoals to a specific reference site. Reference sites were chosen from video data collected from an under water video sled used to map the physical and biological micro and macrohabitat characteristics of the shoals and habitats with uniform depths in the proximity of the shoals (Appendix A). Based on the habitat characteristics shoals were paired with a specific reference site that exhibited similar characteristics (discussed in section 2.2.1 below), but differed only in vertical relief.

2.2.1 Reference Site Selection

Prior to initiating the video survey, we reviewed several sets of bottom habitat information available from other surveys conducted in the study area. This information included underwater vide and profile camera imagery (Cutter and Diaz 2000), fisheries data (Musick 2000; Olney 2000), and bathymetry data (National Geophysical Data Center 2002) from the shoals and nearby deep uniform bottom areas. This information was used to refine our search for potential reference sites close to the study shoals. From this information we identified five potential reference areas to be mapped along with the shoals during the video survey (Figure 2-2). The potential reference sites were chosen in the same general area as the shoals to alleviate any other outside factors such as proximity to shore or separate water masses that could influence species distributions and therefore be misinterpreted as a preference for the shoals or reference sites. In addition, potential reference sites were chosen that exhibited uniform bathymetry (i.e., non-shoal). In the region of the shoals the only areas of uniform bathymetry were deeper areas away from the shoals, and because of this the potential reference sites were generally located in water depths similar to the depths of the shoal bases (Figure 2-1).

Using a transect survey design, we conducted a video survey between the 16th and 19th of September 2002. The video sled was towed off the stern of a 12-m vessel moving at speed of 1.5 to 2.8 knots. Approximately 90-km of bottom habitat was covered during the survey (Figure 2-2). The video sled was equipped with three video cameras mounted in three different configurations to provide a broad overview of the bottom, a near bottom horizontal view to see fish over the bottom and bed form types, and a direct vertical high-resolution view for sediment type and biogenic features (Figure 2-3). All the bottom video footage was recorded on Sony 8-mm video cassettes and Differential Global Positioning System (DGPS) data was collected simultaneously so each video frame could be georeferenced.

When the survey was complete benthic habitats were classified by analyzing videotapes recorded from the horizontal and vertical cameras. Physical and biological micro and macrohabitat features were documented from the recorded videotape at 2.5-minute intervals. Analysis of the videotape was conducted using a Sony editing deck and high-resolution video monitor. Bottom habitats were then classified based on both physical and biological characteristics. Physical characteristics included variables for bedforms type and size, and sediment grain size. Biological characteristics included variables for shell fragment cover, mobile fauna, sedentary fauna, and other biogenic structures (Table 2-1).

Based on a combination of the physical and biological micro and macrohabitat features analyzed from the video footage, four reference sites were chosen, for a total of eight sampling sites (Figure 2-1; Nestlerode and Diaz 2003). Each individual shoal was paired with a reference site that exhibited similar habitat characteristics, but did not exhibit high relief like the shoals (Table A-3). Based on the micro and macrohabitat similarities, reference area two was chosen as Weavers shoals reference, reference area three was designated as Fenwick Island Shoals reference, reference area four was chosen for shoal D, and reference five was selected for Shoal B reference. Reference area one was dropped because it exhibited the least similar habitat characteristics between the shoals (Table A-3). Most of the shoals and their reference sites were between 4.5 and 6.5-km apart, but the site most similar to Weaver shoal was 19-km away from Weaver shoal. The distance between a specific shoal and its reference site does not influence this study, because it is only the habitat similarities that were important when choosing the reference sites, and in general all the reference sites were within 5-km of a shoal (Figure 2-1). For a more thorough description of all the sites and the habitats associated with them see Appendix A; Nestlerode and Diaz 2003.

2.2.2 Fisheries sampling

2.2.2.1 Net Survey

The fisheries sampling began in the fall of 2002 and was conducted seasonally for two years. To maximize the probability of capturing all species that might use the shoals and reference locations during any one season, we reviewed available literature to identify specific times when species densities would be at their highest during any one season. Several documents including, Musick (2000), Olney (2000), Wirth (2001), and the NMFS (2002) web page were synthesized during this review. Information from that review was then used as a guide for planning seasonal sampling events throughout the year.

Fish sampling was conducted using multiple gears with different species and size selectivity to ensure that all fish and mobile benthic species could be sampled. Two different trawls were used to sample fish during the survey. To capture larger mobile species, a 30.5-m “round net” commercial trawl with a with 15-cm stretch mesh body tapering to 5-cm stretch mesh codend was used. Large net sampling was conducted from a 16.5-m wooden stern commercial trawling vessel, the “Tony and Jan” based in Ocean City, MD. Smaller individuals were sampled using a 7.6-m semi-balloon research otter trawl with a with 4-cm stretch mesh body fitted with a 3-mm stretch mesh liner in the codend. Small net trawling was conducted from Versar’s 7.6-m research vessel, the “R/V Integrity.” Commercial trawling speeds were from 3.0 to 3.5 knots, and the small net was trawled at between 1.5 and 2.0 knots. Trawls were deployed for a duration of 10-minutes.

Gillnets were also used to sample large mobile fish species. These nets were deployed from the commercial fishing vessel “Leanna”, based in Ocean City, MD. Gillnets were 30.5-m in length and 3-m deep, consisting of six 30-m panels of varying mesh sizes. By dividing the net into two panels of 7-cm stretch mesh, two panels of 9-cm, and two panels of 15-cm for a total of six panels of three mesh sizes, each net represented one sample with replication. Nets were set on the bottom and were deployed parallel to the current, and were generally fished for an average of four hours.

All organisms were identified to the lowest practical taxon, counted, and a sub-set of 25 specimens of each species were measured to the nearest mm standard length. During each collection, nets were typically deployed in the same general area at each site with replication.

Attempts were made to conduct all net sampling as close together in time as possible during each seasonal sampling event. However, on occasion, unfavorable weather conditions and vessel availability restricted consistent sampling and some time gaps were unavoidable within each seasonal sampling event (Table 2-2).

2.2.2.2 Bioacoustics

In addition to traditional fisheries sampling, we used bioacoustics to compare fish densities and relative biomass between the four study shoals and the four reference sites. Seasonal bioacoustics surveys were conducted in every season except the two winter seasons, when fish densities would be the lowest. Bioacoustics was collected with a Simrad ® EY500, 120-kHz split-beam system. Prior to each seasonal survey the bioacoustic system was calibrated using information from a standard (-40.4 dB) copper sphere and the methods outlined by Brandt (1996). Acoustic data were corrected for signal loss and absorption using standard techniques.

Each seasonal survey included a targeted bioacoustic survey aimed at directly comparing the shoals to reference sites. Surveys consisted of a series of transects across each of the eight study areas, plotted so as to ensure representative coverage of all portions of each area (Table 2-3). An example of eight bioacoustic transects conducted at Fenwick shoal in the spring 2004 survey is presented in Figure 2-4. During each seasonal survey the system transducer was deployed near the water surface (about 1.0 m depth depending upon sea conditions) in a down-looking orientation. The transducer was housed in a tow body that was towed alongside the research vessel during survey tracks at a speed of about 2.5 knots. To insure that cumulative densities and biomass values could be standardized by transect length and referenced geographically, beginning and ending latitude and longitude coordinates were documented for each transect.

During the fall 2002 survey, all acoustic transects were conducted off of either the large fishing vessel during large net trawling, or from the small research vessel provided by Versar, Inc. Trawling operations were conducted entirely during daytime so all acoustic transects were conducted during daytime as well. Due to a relatively low number of acoustic targets satisfying individual target criterion, acoustic data collection during all subsequent seasonal surveys were conducted at night. Night acoustic surveys have typically produced higher numbers of individual targets due to fish dispersal from schools and the tendency for fish to move off of the bottom at night. A total of 45, 64, and 62 transects were completed during fall 2002, spring 2003 and summer 2003 surveys. During fall 2003, spring 2004 and summer 2004, 64 transects were completed in each seasonal survey (Table 2-4). At each site, transects were replicated from 4-8 times during fall-02 and 7-8 times for all other seasonal sampling. Depths over which bioacoustic transects were performed varied throughout the sampling sites with average depths of 7, 10, 6, and 7 meters at Shoal B, D, Fenwick Island, and Weaver respectively and an average depth of 12-m at the reference sites.

Bioacoustic data were processed on a microcomputer using EchoView ® 3.00.81 software (SonarData, Pty Ltd, Hobart, Australia). A minimum threshold value of –50 dB was used in processing of acoustic data to eliminate very small targets from contributing to densities that might be finfish species. A threshold value of –50 dB would be similar to the backscatter received from a small (e.g. 35-mm) fish.

Table 2-1. Latitude and longitude locations of four shoals and four reference sites sampled of the coast of Maryland and Delaware using trawls, gillnets and bioacoustics from November 2002 until September 2004. The minimum and maximum sampling depths for net sampling are also presented.

Site	**Location (Degrees Decimal Minutes)**		**Sampling Depths (m)**	
	Latitude	**Longitude**	**Minimum**	**Maximum**
Fenwick Shoal	38^{0} 27.21	74^{0} 56.07	5	9
Fenwick Reference	38^{0} 26.23	74^{0} 52.34	14	19
Weaver Shoal	38^{0} 25.38	74^{0} 55.22	7	10
Weaver Reference	38^{0} 14.50	74^{0} 57.25	12	18
Shoal B	38^{0} 17.41	74^{0} 53.24	8	11
Shoal B Reference	38^{0} 20.41	74^{0} 54.09	13	22
Shoal D	38^{0} 15.43	74^{0} 51.52	10	16
Shoal D Reference	38^{0} 19.56	74^{0} 50.49	12	22

Table 2-2. Physical and biological micro and macrohabitat features measured at four shoals and five uniform-bottom sites off the coast of Maryland and Delaware using underwater video images. All variables are classified as present or absent, except burrows and tubes, which were counted.

Physical Characteristics

Bedform size and shape:
- Large bedforms, wavelength 30 cm or more
- Small bedforms, wavelength less than 30 cm
- None, no bedforms, flat relatively even bottom.

Bedform shape:
- Smooth crested, with top of bedform rounded
- Sharp crested, with top of bedform peaked

Sediment type:
- Fine to medium sand
- Medium to coarse sand
- Coarse sand to small granules

Biological Characteristics

Shell cover:
- <10% of the bottom covered by shell and shell fragments.
- >10% of the bottom covered by shell and shell fragments.

Biogenic structure:
- No biology obvious
- Burrow opening, tubes, or sessile fauna present

Table 2-3. Beginning and ending dates from all seasonal net surveys conducted at four shoals and four reference sites off the coast of Maryland and Delaware from November 2002 until September 2004

Season	**Dates**		**Gear**		
	Begin	**End**	**Commercial Trawl**	**Research Trawl**	**Gillnet**
Fall 02	11/19/02	12/19/02	16	16	16
Winter 03	03/10/03	03/25/03	16	16	16
Spring 03	05/29/03	06/10/03	16	16	16
Summer 03	08/10/04	10/03/03	16	16	16
Fall 03	11/11/03	11/18/03	16	16	16
Winter 04	02/04/04	02/24/04	16	16	16
Spring 04	05/25/04	06/02/04	16	16	16
Summer 04	08/09/04	08/19/04	16	16	16
Total Samples			128	128	128

Table 2-4. Total number of bioacoustic transects performed at four shoals and four reference sites off the coast of Maryland and Delaware from six seasonal surveys conducted from November 2002 to September 2004.

	Season						
	Site	**Fall 2002**	**Spring 2003**	**Summer 2003**	**Fall 2003**	**Spring 2004**	**Summer 2004**
Shoal	Fenwick	6	8	8	8	8	8
	Weaver	4	8	8	8	8	8
	Shoal B	8	8	8	8	8	8
	Shoal D	6	8	8	8	8	8
Reference	Fenwick	5	8	7	8	8	8
	Weaver	6	8	7	8	8	8
	Shoal B	5	8	8	8	8	8
	Shoal D	5	8	8	8	8	8
Total		45	64	62	64	64	64

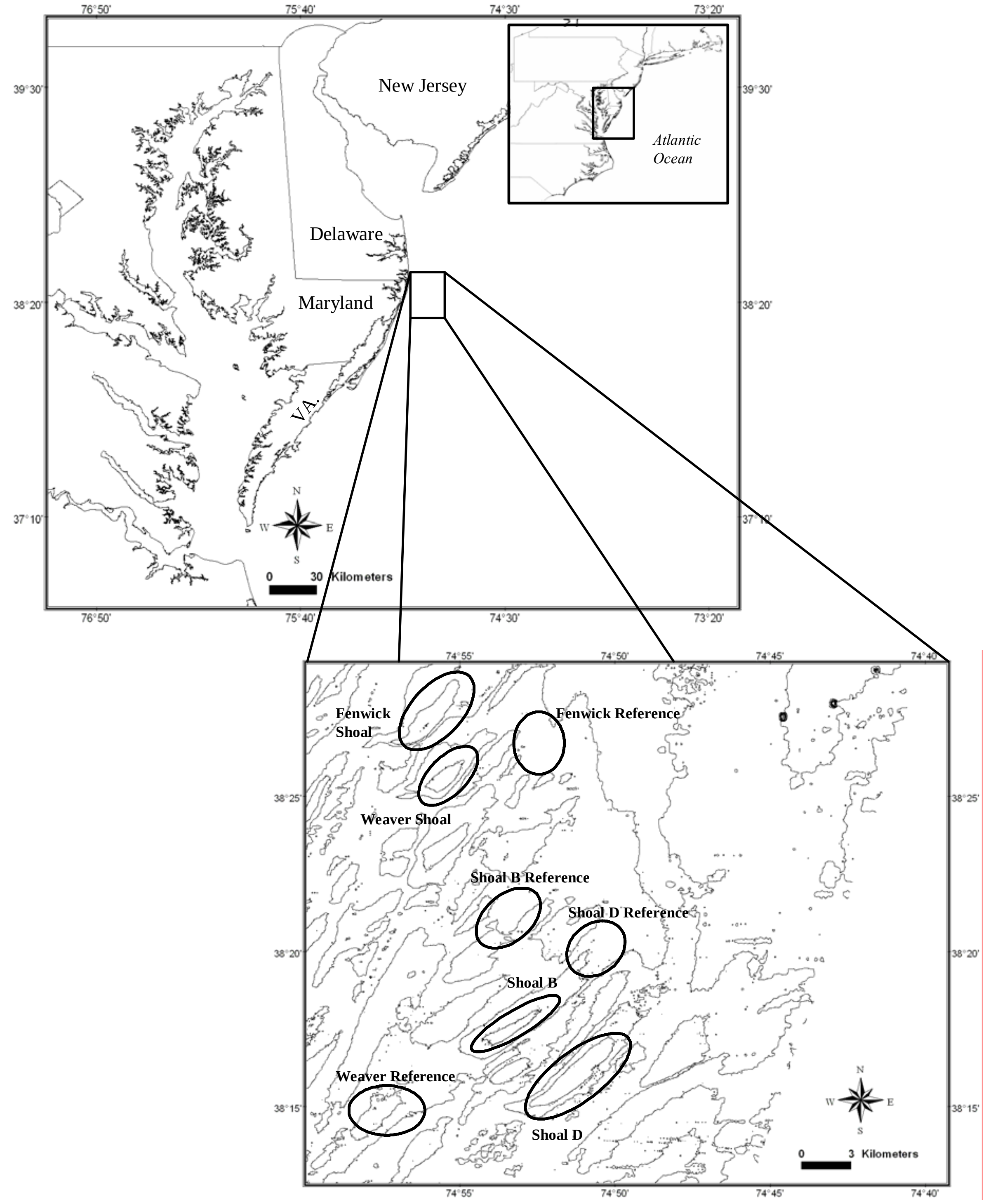


Figure 2-1. Map of four shoals and four reference sites sampled for marine biota off the coast of Maryland and Delaware using trawls, gillnets and bioacoustics from November 2002 until September 2004.

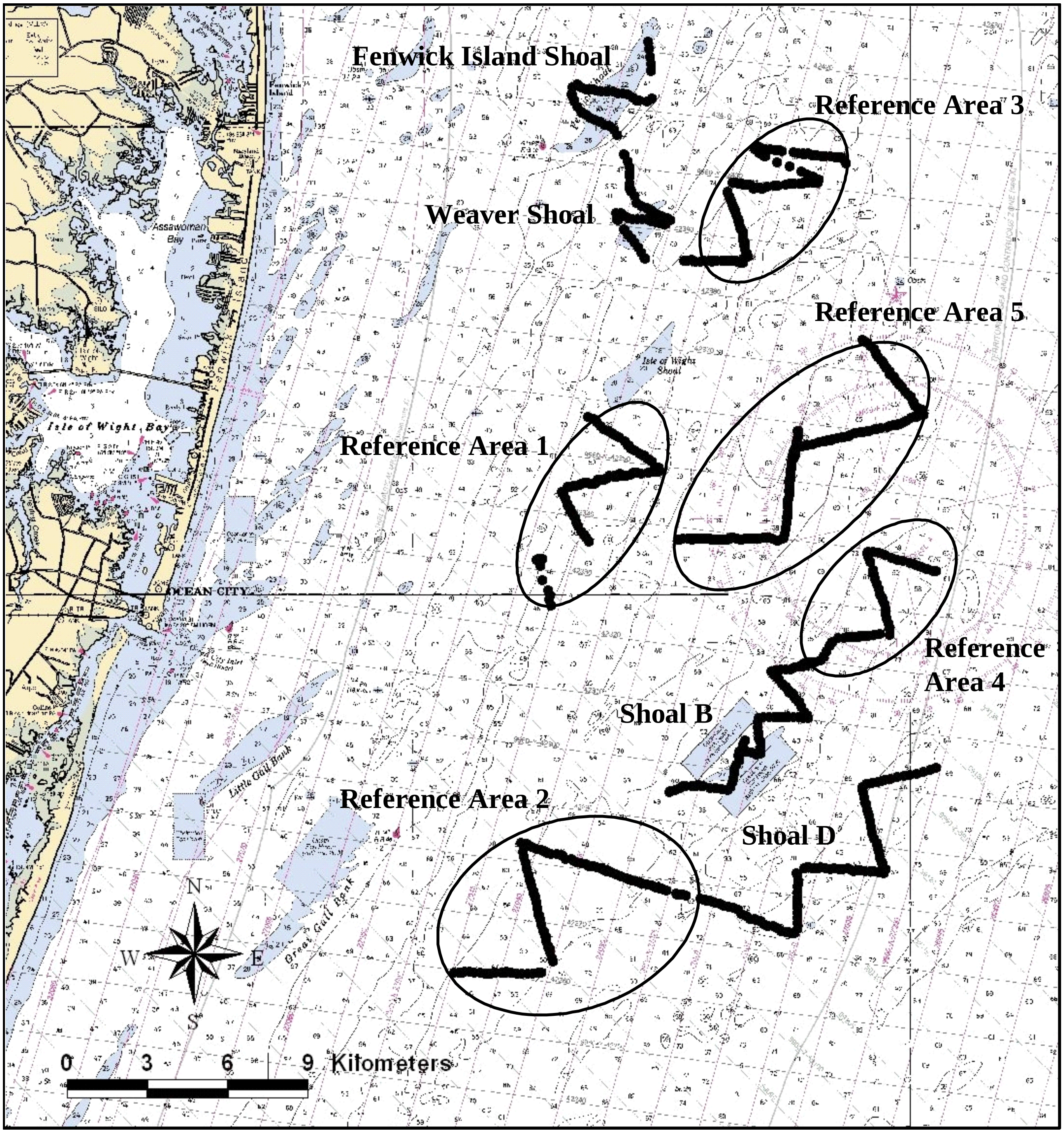


Figure 2-2. Locations of five potential reference sites and four shoals with video transect lines followed in the September 2002 underwater video survey off the coast of Maryland and Delaware. All sites are labeled with potential reference sites circled and shoals not circled.

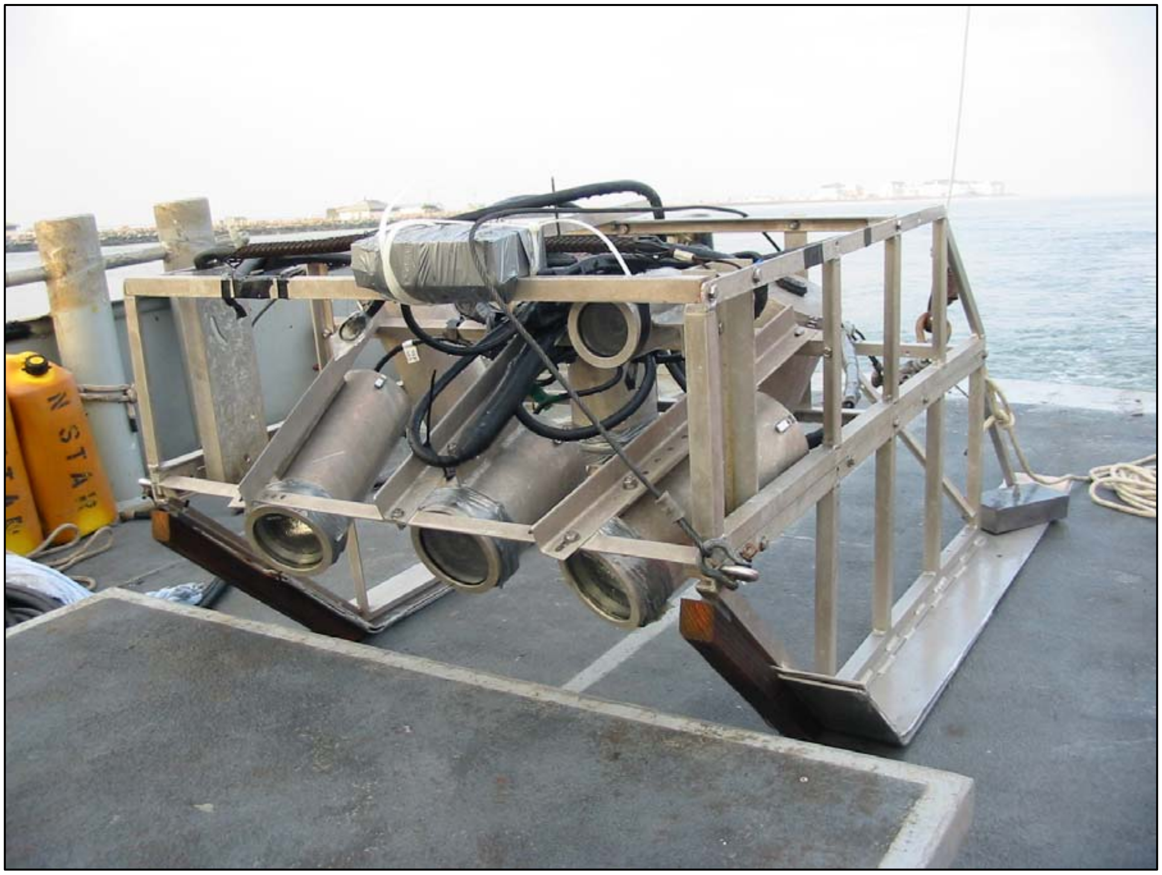


Figure 2-3. Video sled used to characterize benthic habitats. Overview camera is at the top right corner of the sled, horizontal camera is in the front center and flanked by two electronic video strobes, close-up vertical camera is in the center of the sled, behind the horizontal camera. Sled runners are 0.8 m apart.

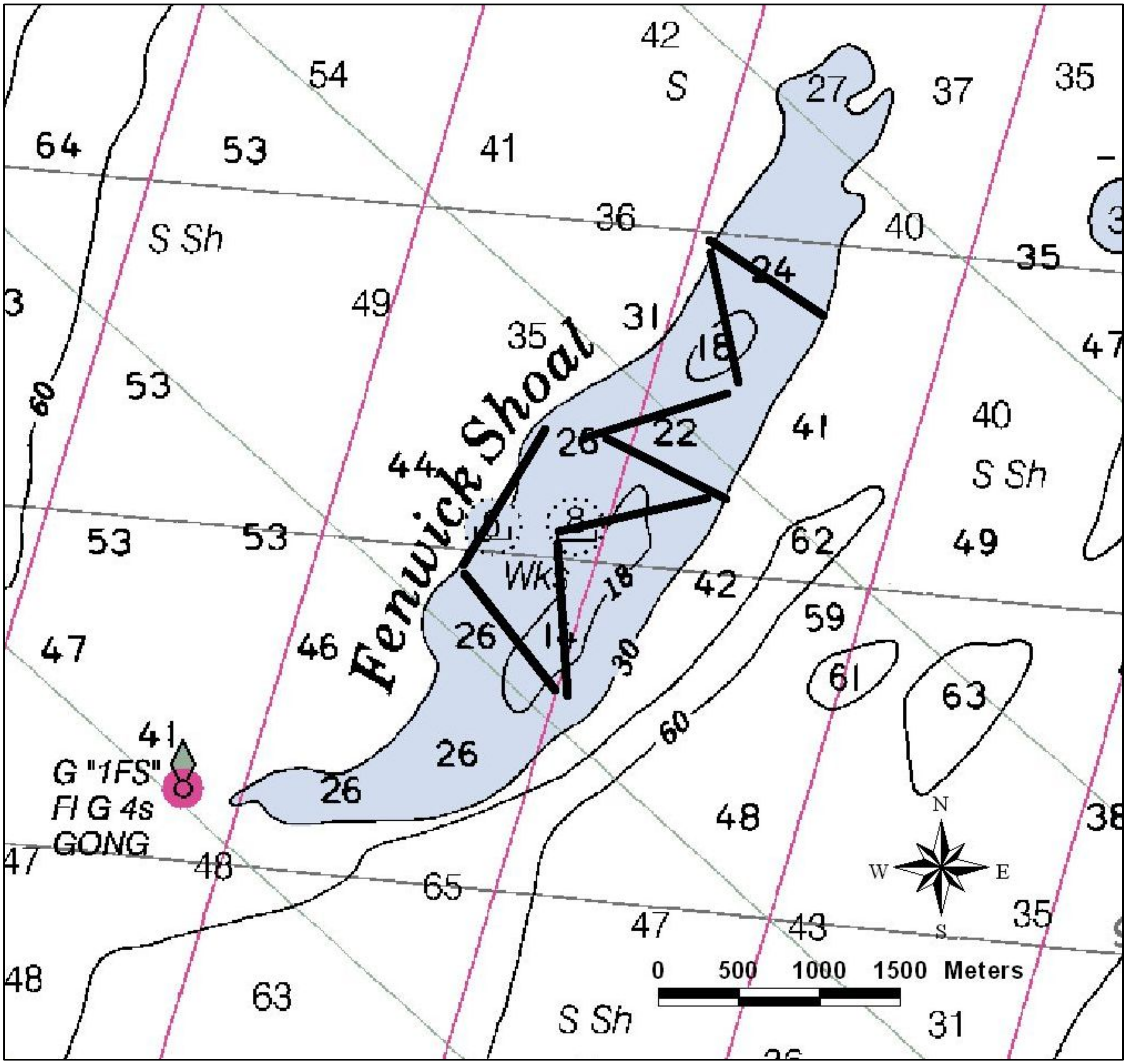


Figure 2-4. Map of Fenwick Island Shoal with eight transect lines completed in the spring 2004 bioacoustic survey off the coast of Maryland and Delaware as one part of a fisheries study conducted between November 2002 and September 2004. Depths are in feet.

3.0 STATISTICAL ANALYSIS OF NET SURVEY DATA

3.1 TOTAL CATCH ANALYSIS

3.1.1 Total Catch Analysis Methods

All catch data were summarized by season and site. We tested for differences in total species relative abundance (CPUE), total species richness, and total species diversity between shoals and reference site habitats, individual shoals and reference sites, for all years combined and for individual seasons. Since differences in catch efficiencies were present between all gears, all tests were gear specific. Catch data were standardized to catch per unit of effort (CPUE) before analysis, where units were the number of animals captured per 500 m (1640 ft) trawled in small trawls, 1000m (3280 ft) per commercial trawl, and number captured per hour of soak time in gillnets. These estimates were transformed to $\log_e$ (CPUE + 1) before analysis to meet the assumption of equal variance among treatments for ANOVA. We conducted ANOVA with $\log_e$ (CPUE +1) as the response variable, site and season as blocks, and treatment (shoal or reference) as a factor, using the SAS GLM procedure (SAS Institute 2004). Community diversity was tested on the transformed CPUE data and was calculated using the Shannon index.

The formula for the calculation of the Shannon-Wiener Index is:

$$H = -\sum_{i=1}^{s} (p_i)(\log_2 p_i)$$

where

H = index of species diversity
S = number of species
p_i = proportion of total sample belonging to ith species

Because three separate gears were used to target specific portions of the species populations residing on the shoal and reference site habitat a qualitative description of the catch is given for each gear type.

3.1.2 Total Catch Analysis Results

Overall, 41,893 individuals were collected from a combination of 384 small trawl (n=128), commercial trawls (n=128) and gillnet sets (n=128). In the collections there were a total of 57 species of fish including 15 species of sharks, skates, and rays (Table 3-1). In addition, there were 17 invertebrate species represented by 7 decapod crustations and 10 other invertebrate species. Seasonal gear comparisons between the reference sites revealed few significant differences in measured values between individual seasons or combined seasons, and no overall patterns of higher values at one site or another Between shoal comparisons were similar with few significant differences between the shoals seasonally or when all years were combined. Like the reference sites, no patterns of higher or lower measured values at a particular shoal were evident.

Comparisons between shoals and reference sites for each season and gear showed mixed results with generally higher numbers of total species abundance, species richness, and species diversity at the reference sites in trawls and no clear patterns in gillnet data. There were significant seasonal differences in species densities throughout the study at all the sampling sites and between all gears. There were also differences in catch between all gears within a season. Therefore an overall description of total species abundance, species richness, and species diversity by gear is presented below.

The information from the net survey data described here and in Appendices B, C, and D presents our study in several different configurations designed to assist the reader in the fullest interpretation. Specific configurations are 1) all the shoals and reference site data combined with both yearly seasonal samples combined, 2) all the shoals and reference site data combined for every season sampled, 3) all sampling sites presented with both yearly seasonal samples combined, and 4) all sampling sites presented for every season sampled. We believe the latter format is the most germane for this study and therefore the seasonal descriptions by gear is presented with an emphasis on all sites with both years of data combined.

Table 3-1. Species list of fish and mobile benthos and associated guild collected at four shoal and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.

Taxonomic Name	Common Name
Benthic Finfish	
Ammodytes americanus	American sand lance
Astroscopus guttatus	Northern stargazer
Centropristis striata	Black sea bass
Cynoscion regalis	Weakfish
Dasyatis centroura	Roughtail stingray
Etropus microstomus	Smallmouth flounder
Gadus morhua	Atlantic cod
Gymnura micrura	Smooth butterfly ray
Hippocampus erectus	Lined seahorse
Leiostomus xanthurus	Spot
Lophius americanus	Goosefish
Menticirrhus saxatilis	Northern kingfish
Micropogonias undulatus	Atlantic croaker
Morone saxatilis	Striped bass
Mustelus canis	Smooth dogfish
Myliobatis freminvillei	Bullnose ray
Ophidion marginatum	Striped cusk-eel
Paralichthys dentatus	Summer flounder
Pleuronectes americanus	Winter flounder
Prionotus carolinus	Northern searobin
Prionotus evolans	Striped searobin
Raja eglanteria	Clearnose skate
Raja erinacea	Little skate
Raja laevis	Barndoor skate
Raja ocellata	Winter skate
Rhinoptera bonasus	Cownose ray
Rhizoprionodon terraenovae	Atlantic sharpnose shark
Scophthalmus aquosus	Windowpane
Sphoeroides maculatus	Northern puffer
Squalus acanthias	Spiny dogfish
Squatina dumeril	Atlantic angel shark
Stenotomus chrysops	Scup
Syngnathus fuscus	Northern pipefish
Synodus foetens	Inshore lizardfish
Urophycis chuss	Red hake
Urophycis regia	Spotted hake

Table 3-1. (Continued)

Taxonomic Name	Common Name
Pelagic Finfish	
Alopias vulpinus	Thresher shark
Alosa aestivalis	Blueback herring
Alosa mediocris	Hickory shad
Alosa pseudoharengus	Alewife
Alosa sapidissima	American shad
Anchoa hepsetus	Striped anchovy
Anchoa mitchilli	Bay anchovy
Brevoortia tyrannus	Atlantic menhaden
Caranx crysos	Blue runner
Carcharhinus obscurus	Dusky shark
Carcharhinus plumbeus	Sandbar shark
Clupea harengus harengus	Atlantic herring
Menidia menidia	Atlantic silverside
Merluccius bilinearis	Silver hake
Peprilus alepidotus	Harvestfish
Peprilus triacanthus	Butterfish
Pomatomus saltatrix	Bluefish
Rachycentron canadum	Cobia
Sarda sarda	Atlantic bonito
Scomber scombrus	Atlantic mackerel
Scomberomorus maculatus	Spanish mackerel
Benthic Invertebrate	
Asteroidea	Starfishes
Busycon carica	Knobbed whelk
Busycotypus canaliculatus	Channeled whelk
Callinectes sapidus	Blue crab
Cancer irroratus	Atlantic rock crab
Crangon septemspinosa	Sand shrimp
Echinoidea	Heart urchins
Gastropoda	Gastropods
Libinia emarginata	Portly spider crab
Limulus polyphemus	Horseshoe crab
Nudibranchia	Nudibranchs
Octopus vulgaris	Common octopus
Ovalipes ocellatus	Lady crab
Ovalipes stephensoni	Coarsehand lady crab
Paguridae	Right-handed hermit crabs
Polinices	Moon snails
Pelagic Invertebrate	
Cephalopoda	Squids

3.1.2.1 Small Trawls

Small trawling was conducted at all the sites and in every season throughout the entire study. However, because of problems associated with the gear (a double cable instead of a single bridal was used which did not effectively sample deep stations) during the first sampling season (fall 2002), data from that season and year is excluded from any analysis regarding small trawls.

Small trawls were used to characterize smaller individual species and the early life stages of species present at the shoals and reference sites. On average, total abundance was consistently higher at the reference sites when compared to the shoals (Table 3-2 and 3-3; Figures 3-1 and 3-2). However, on some occasions throughout the study, some of the shoals exhibited higher total abundance than their paired reference site (Table 3-4 and 3-5; Figures 3-3 and 3-4).

A total of 41 different species of fish and invertebrates were collected in the small trawls at the shoals and reference sites during the course of the study (Table B-1). Total species richness was generally highest at the reference sites during each season (Table 3-2 and 3-3; Figure 3-1 and 3-2). Twenty-four fish and 15 invertebrate species were collected at the reference sites as opposed to 19 fish and 14 invertebrates collected at the shoals. Among those species, six fish and two invertebrate species collected at the reference sites were never collected on the shoals, and only two species, the blue crab and inshore lizard fish were found only on the shoals.

Right-handed hermit crabs and starfish were the most abundant organisms over the two-year study (Table B-1). These two species were also the most frequently collected species, with right-handed hermit crabs present at all stations in every season and starfish present at most of the stations in every season (Table B-7). Among the fish species collected, spotted hake was the most common, and spotted hake and northern searobin were the most abundant over all the sites during the two years of sampling (Table B-7 and B-9).

<u>Fall</u>

In the fall (2003) collection, catch per unit of effort was mixed between shoal and the reference sites (Table 3-4; Figure 3-3). Both Fenwick Island (33±10.49 SE) and Weaver (98.38±18.5 SE) shoal were higher in total abundance when compared to their paired reference sites (16.7±0.82 SE and 69.81±10.25 SE, respectively). Conversely, Shoal D and B exhibited lower abundances than their reference sites, with Shoal B having significantly less abundance than its reference site (Table 3-4).

Total species richness was similar between paired sites in the fall, with Shoal B Reference exhibiting the highest average species number (Table 3-4). A total of 15 fish and 9 invertebrates were collected at all sites in the fall, with 14 fish species and 8 invertebrates at the reference sites compared to 11 fish and 7 invertebrates at the shoals (Table B-1). The mean Sannon-Weaver index of diversity was similar between all sites with the highest diversity at Shoal B Reference (2.73±0.12 SE) and the lowest at Shoal D Reference (1.43±0.22 SE).

Starfish were collected at all but one of the sites (Table B-7), and accounted for 36% of the entire combined catch. Right-handed hermit crab was the second most abundant species comprising 19% of the catch and was present at every site (Table B-7). Starfish was also the most abundant invertebrate collected on the shoals, but was not as abundant as squid at the reference sites (Figure B-1). Spotted hake and smallmouth flounder were the most frequently occurring fish species, collected at nearly every site (Table B-7). Atlantic croaker was the most abundant fish species overall with higher abundance at the reference sites than at the shoals (Table B-3). The second most abundant fish overall and the most abundant at the shoals was the spotted hake (Table B-2). Of the 22 total species collected at the reference sites in the fall, six of them were not present on the shoals and only two species, the little skate and moon snails, were found on shoals and not in a reference site.

Winter

Overall, total abundance on shoals and reference sites in the winter sampling was lower than that of any other season (Table 3-4; Figure 3-3). Total abundance was higher at the reference sites for all paired sites but Weaver Shoal, and the difference between Weaver and its reference was minimal (Table 3-4; Figure 3-3). No significant differences in abundance were detected between shoals and their reference sites (Table 3-4). The reference site for Shoal D exhibited the highest abundance (33.1±18.37 SE) in winter and Shoal B had the lowest (11.27±4.98 SE).

Total species richness was also lowest compared to all other seasons (Table 3-4), and invertebrates were more common than fish accounting for 83% of the entire collection (Table B-8). A total of 8 fish and 10 invertebrate species were collected overall. Shoals always had less species than the paired reference sites (Table 3-4). A total of 6 fish and 6 invertebrates were collected at the shoals, and 8 fish and 9 invertebrates were collected at the reference sites. Four invertebrate and two fish species were found only on the reference sites and only the portly spider crab was collected on the shoals. In addition, species diversity was also lower on the shoals than on the reference sites (Table 3-4).

Sand shrimp and right-handed hermit crabs were the most abundant species and most prevalent species collected throughout the study sites in the winter (Table B-7; Figure B-1). Sand shrimp occurred at every site and accounted for 36% of the catch at shoals and 28% of the catch at the reference sites. Although right-handed hermit crabs had higher abundance overall, the second most abundant invertebrate species collected at the reference sites was moon snails (17%). Gastropods (21%) were the second most abundant invertebrate collected on shoals.

Very few fish were collected during winter sampling (Table B-8 and B-9). In general, fish were not as abundant as invertebrate species accounting for only 17% of the entire winter collection. Spotted hake was the most abundant fish at both shoals and reference sites, representing over half of all fish collected (Table B-3). The next most common fish was the little skate, which made up 13% of the fish species and was evenly distributed across shoals and reference sites (Table B-7).

Spring

In the spring, total abundance was mixed between shoal and reference sites (Table 3-4; Figure 3-3). Both Shoal D (35.31±20.33 SE) and Weaver Shoal (46.12±26.05 SE) were higher in total abundance when compared to their paired reference sites (29.59±20.89 SE and 19.09±8.42 SE, respectively). Conversely, Shoal B Reference had significantly higher total abundance than did Shoal B (Table 3-4), and Fenwick reference (38.29±14.76 SE) had slightly higher abundance than Fenwick Shoal (33.75±22.21 SE).

The total number of species collected throughout the sites in the spring was the third highest for all the seasons (Table 3-4; Figure 3-1), with a total of 14 fish and 12 invertebrates collected. Overall, invertebrates were more abundant than fish accounting for 77% of the entire collection. Total species richness varied between shoals and reference sites, with the sites that exhibited high total abundance also showing higher total species richness (Table 3-4). For example, abundance was higher at Shoal B Reference site with an average of 9 species compared to Shoal B which averaged only 4 species and had lower total abundance. A total of 11 fish and 9 invertebrates were collected on shoals compared to 12 fish and 11 invertebrates on the reference sites. Because sites with higher abundance also exhibited higher total species richness, diversity values followed the same trend, with the highest species diversity at Shoal B Reference (2.38±0.54 SE) and the lowest at Fenwick Shoal (1.32±0.55 SE). Of the 26 species collected at the reference sites in the spring, five of them were not present at the shoals and only two species, the clearnose skate and horseshoe crab, were found on shoals and not in a reference site.

Squids and right-handed hermit crabs were the most abundant and most prevalent species throughout the spring collections (Table B-7; Figure B-2). Both squids and right-handed hermit crabs were also the most abundant invertebrates on the shoals (Table B-1). These two species accounted for more than half of all species collected at the shoals. Squid accounted for 35% and right-handed hermit crabs accounted for 26% of all invertebrates at shoals. Squid and starfish were the most abundant invertebrates at the reference sites accounting for over 30% of all collected species and 53% of all invertebrates collected at reference sites combined.

Fish species accounted for only 12% of the total catch on the shoals and 36% of the catch at the reference sites. Spotted hake was the most abundant fish species overall (Table B-8), but was more common at the reference sites than on the shoals, accounting for 48% of all fish collected at the reference sites. Northern sea robin was the second most abundant fish overall, exhibiting higher abundance at the reference sites than at the shoals (Table B-8 and B-9). Northern sea robin accounted for 24% of all fish species collected at the reference sites and for 15% of fish at the shoals.

Summer

Total abundance in the summer sampling at shoals and reference sites was slightly higher than the fall season (Table 3-4; Figure 3-3). Overall no significant differences in abundance were detected between shoals or reference sites, but total abundance was generally higher at the reference sites than at shoals for all paired sites (Table 3-4). Shoal B Reference site exhibited the highest abundance (126.26±75.81 SE) in summer and Shoal B had the lowest (23.89±3.27 SE).

Even though the total number of species collected throughout all the sites was higher than any other season, the average total species richness at individual sites was slightly lower than the fall sampling (Table 3-4; Figure 3-3). A total of 19 fish and 12 invertebrate species were collected throughout the sites, with invertebrates being more abundant than fish (Table B-1). The total number of invertebrate species were similar between references (n=9) and shoal (n=10) collections, and more fish species were collected at the reference sites than at the shoals, with 19 species at the reference sites compared to only 9 species collected at the shoals. Species diversity was found to be significantly different between Fenwick Shoal reference (2.19±0.19 SE) and Fenwick Island Shoal (0.75±0.26), but all other paired sites exhibited similar diversities (Table 3-4). Shoal B was found to have the highest diversity in the summer, and Fenwick Shoal had the lowest (Table 3-4; Figure 3-3). Of the 31 species collected in the summer, 12 occurred only at reference sites and 5 species were found only at the shoals.

Right-handed hermit crabs and squid were the most abundant species and most prevalent species collected throughout the study sites in the summer (Table B-7; Figure B-2). Right-handed hermit crabs were found in greater abundance at the shoals (52%) compared to reference sites (8%). Squid was more abundant at the reference sites accounting for 41% of the total catch at reference sites and 66% of the total invertebrates collected.

In the summer collections, fish accounted for 28% of the entire catch over all the sites (Table B-2). Even though it was not present at any of the shoal sites, overall bay anchovy was the most abundant fish species collected, accounting for 27% of the fish collected and 41% of all the fish collected at the reference sites. The second most abundant fish was northern sea robin (Table B-8 and B-9). This species was collected at every site, but was more abundant at the reference sites than at the shoals (Table B-7). Conversely, scup was also collected at every site, but was more abundant at shoals than at the reference sites.

Table 3-2. Combined two-year seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in small trawls at four shoal and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004. Significant differences between shoal and reference sites from ANOVA tests are highlighted.

Season	Site	Mean Total CPUE	Mean Number of Spp	Mean Shannon
Fall 03	Ref	85.32 +/- 23.2	9.13 +/- 1.38	2.07 +/- 0.28
	Shoal	40.69 +/- 13.61	7.75 +/- 0.75	2.2 +/- 0.17
Winter	Ref	27.37 +/- 5.8	5.31 +/- 0.44	1.88 +/- 0.11
	Shoal	14.98 +/- 2.96	4 +/- 0.45	1.6 +/- 0.16
Spring	Ref	30.38 +/- 6.45	6.63 +/- 0.96	1.83 +/- 0.21
	Shoal	31.76 +/- 9.58	5.75 +/- 1.04	1.61 +/- 0.25
Summer	Ref	96.76 +/- 26.41	7.94 +/- 0.95	1.86 +/- 0.23
	Shoal	43.2 +/- 11.49	6.25 +/- 0.79	1.59 +/- 0.18

* Highlighted denotes significant difference (alpha = 0.05)

Table 3-3. Seasonal mean (and SE) total species CPUE, number of species, and species diversity collected in small trawls at four shoal and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004. Significant differences between shoal and reference sites from ANOVA tests are highlighted.

Season	Site	Mean Total CPUE	Mean Number of Spp	Mean Shannon
Winter 03	Ref	31.13 +/- 7.2	6.25 +/- 0.65	2.17 +/- 0.08
	Shoal	12.37 +/- 4.75	4.13 +/- 0.85	1.6 +/- 0.3
Spring 03	Ref	15.57 +/- 2.75	4.63 +/- 0.96	1.47 +/- 0.24
	Shoal	5.26 +/- 2.25	2.63 +/- 0.92	0.92 +/- 0.32
Summer 03	Ref	56.79 +/- 23.3	7.5 +/- 1	2.01 +/- 0.19
	Shoal	14.77 +/- 4.04	4.13 +/- 0.91	1.36 +/- 0.27
Fall 03	Ref	85.32 +/- 23.2	9.13 +/- 1.38	2.07 +/- 0.28
	Shoal	40.69 +/- 13.61	7.75 +/- 0.75	2.2 +/- 0.17
Winter 04	Ref	23.61 +/- 9.4	4.38 +/- 0.38	1.59 +/- 0.14
	Shoal	17.59 +/- 3.61	3.88 +/- 0.35	1.6 +/- 0.15
Spring 04	Ref	45.18 +/- 10.4	8.63 +/- 1.36	2.2 +/- 0.3
	Shoal	58.27 +/- 13.7	8.88 +/- 1.01	2.3 +/- 0.16
Summer 04	Ref	136.72 +/- 44.6	8.38 +/- 1.67	1.71 +/- 0.44
	Shoal	71.63 +/- 17.86	8.38 +/- 0.75	1.83 +/- 0.21

Table 3-4. Combined two-year seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in small trawls at eight sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004. Significant differences between paired sites from ANOVA tests are highlighted.

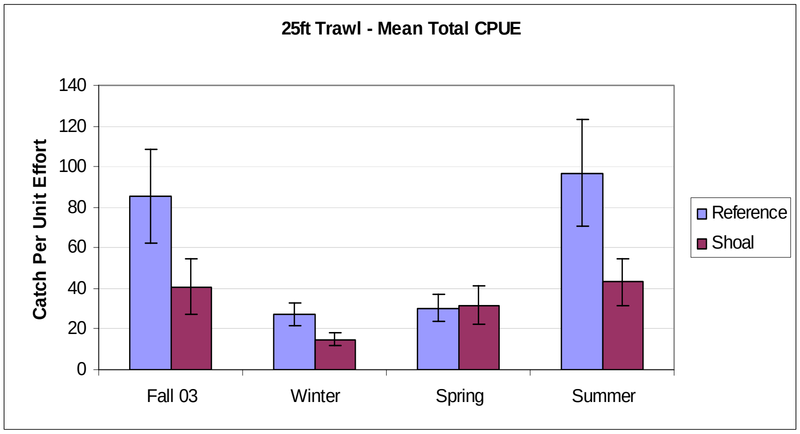
Season	Site	Mean Total CPUE	Mean Number of Spp	Mean Shannon
Fall 03	Fenwick Island Shoal	33 +/- 10.49	8 +/- 0	2.47 +/- 0.03
	Fenwick Reference	16.7 +/- 0.82	6.5 +/- 2.5	2.27 +/- 0.48
	Shoal B	9.17 +/- 2.66	4.5 +/- 0.5	2.06 +/- 0.17
	Shoal B Reference	136.51 +/- 61.54	13 +/- 2	2.73 +/- 0.12
	Shoal D	22.19 +/- 0.74	9 +/- 0	2.71 +/- 0.09
	Shoal D Reference	118.25 +/- 50.23	8 +/- 2	1.43 +/- 0.22
	Weaver Shoal	98.39 +/- 18.5	9.5 +/- 0.5	1.54 +/- 0.16
	Weaver Reference	69.81 +/- 10.25	9 +/- 4	1.86 +/- 1.01
Winter	Fenwick Island Shoal	17.59 +/- 7.46	4.75 +/- 1.11	1.83 +/- 0.28
	Fenwick Reference	28.59 +/- 12.85	5.25 +/- 1.44	1.8 +/- 0.23
	Shoal B	11.27 +/- 4.98	3.75 +/- 0.85	1.61 +/- 0.34
	Shoal B Reference	29.91 +/- 11.16	5.75 +/- 1.11	1.93 +/- 0.16
	Shoal D	12.5 +/- 7.99	3.5 +/- 1.26	1.35 +/- 0.54
	Shoal D Reference	33.1 +/- 18.37	5.25 +/- 0.48	2.05 +/- 0.15
	Weaver Shoal	18.55 +/- 4.23	4 +/- 0.41	1.6 +/- 0.1
	Weaver Reference	17.89 +/- 1.56	5 +/- 0.41	1.76 +/- 0.33
Spring	Fenwick Island Shoal	33.75 +/- 22.21	5.5 +/- 2.4	1.32 +/- 0.55
	Fenwick Reference	38.29 +/- 14.76	7.5 +/- 1.76	2.15 +/- 0.38
	Shoal B	11.87 +/- 6.74	4.25 +/- 0.63	1.8 +/- 0.1
	Shoal B Reference	34.54 +/- 6.14	9 +/- 2.04	2.38 +/- 0.54
	Shoal D	35.31 +/- 20.33	6.25 +/- 3.35	1.41 +/- 0.82
	Shoal D Reference	29.59 +/- 20.89	4.75 +/- 1.8	1.39 +/- 0.27
	Weaver Shoal	46.12 +/- 26.05	7 +/- 1.73	1.89 +/- 0.39
	Weaver Reference	19.09 +/- 8.42	5.25 +/- 1.97	1.42 +/- 0.35
Summer	Fenwick Island Shoal	42.73 +/- 27.73	4.5 +/- 2.1	0.75 +/- 0.26
	Fenwick Reference	112.67 +/- 38.88	9.5 +/- 1.32	2.19 +/- 0.19
	Shoal B	23.89 +/- 3.27	7 +/- 1.08	2.22 +/- 0.33
	Shoal B Reference	126.26 +/- 75.81	9.25 +/- 2.02	2.17 +/- 0.6
	Shoal D	37.51 +/- 14.57	6.25 +/- 0.85	1.73 +/- 0.25
	Shoal D Reference	81.19 +/- 60.96	7 +/- 1.47	2 +/- 0.34
	Weaver Shoal	68.68 +/- 36.03	7.25 +/- 2.17	1.67 +/- 0.13
	Weaver Reference	66.91 +/- 47.11	6 +/- 2.65	1.07 +/- 0.54

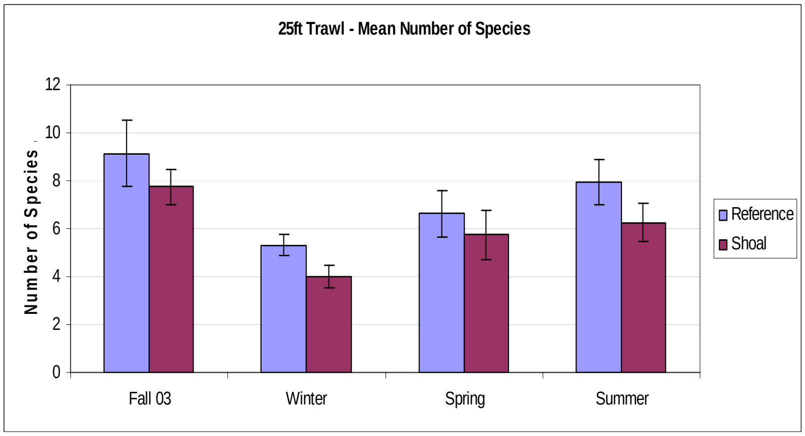
Table 3-5. Seasonal mean (and SE) total species CPUE, number of species, and species diversity collected in small trawls at eight sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004. Significant differences between paired sites from ANOVA tests are highlighted.

Season	Site	Mean Total CPUE	Mean Number of Species	Mean Shannon
Winter 03	Fenwick Island Shoal	22.24 +/- 16.92	5.5 +/- 2.5	1.99 +/- 0.62
	Fenwick Reference	50.78 +/- 1.65	7.5 +/- 1.5	2.19 +/- 0.11
	Shoal B	4.52 +/- 0.68	3 +/- 1	1.46 +/- 0.46
	Shoal B Reference	43.72 +/- 18.95	6.5 +/- 2.5	2.06 +/- 0.35
	Shoal D	5.88 +/- 4.78	4 +/- 3	1.31 +/- 1.31
	Shoal D Reference	12.74 +/- 0.38	5.5 +/- 0.5	2.25 +/- 0.21
	Weaver Shoal	16.84 +/- 10.03	4 +/- 1	1.62 +/- 0.07
	Weaver Reference	17.29 +/- 3.68	5.5 +/- 0.5	2.18 +/- 0.05
Spring 03	Fenwick Island Shoal	3.84 +/- 3.84	1.5 +/- 1.5	0.49 +/- 0.49
	Fenwick Reference	13.95 +/- 1.37	4.5 +/- 0.5	1.52 +/- 0.27
	Shoal B	4.86 +/- 1.45	3.5 +/- 0.5	1.67 +/- 0.17
	Shoal B Reference	24.72 +/- 5.6	6.5 +/- 3.5	1.74 +/- 0.96
	Shoal D	0.52 +/- 0.52	0.5 +/- 0.5	0 +/- 0
	Shoal D Reference	8.8 +/- 5.04	3 +/- 1	1.29 +/- 0.29
	Weaver Shoal	11.79 +/- 7.56	5 +/- 3	1.5 +/- 0.78
	Weaver Reference	14.82 +/- 4.51	4.5 +/- 2.5	1.33 +/- 0.68
Summer 03	Fenwick Island Shoal	2.16 +/- 2.16	1 +/- 1	0.49 +/- 0.49
	Fenwick Reference	68.13 +/- 7.15	7.5 +/- 0.5	1.92 +/- 0.07
	Shoal B	20.1 +/- 1.73	6 +/- 2	1.92 +/- 0.66
	Shoal B Reference	29.05 +/- 18.76	7.5 +/- 1.5	2.47 +/- 0.18
	Shoal D	28.9 +/- 3.62	5.5 +/- 1.5	1.42 +/- 0.43
	Shoal D Reference	12.45 +/- 7.62	5 +/- 2	1.74 +/- 0.6
	Weaver Shoal	7.91 +/- 1.37	4 +/- 1	1.6 +/- 0.3
	Weaver Reference	117.53 +/- 90.46	10 +/- 3	1.89 +/- 0.56
Fall 03	Fenwick Island Shoal	33 +/- 10.49	8 +/- 0	2.47 +/- 0.03
	Fenwick Reference	16.7 +/- 0.82	6.5 +/- 2.5	2.27 +/- 0.48
	Shoal B	9.17 +/- 2.66	4.5 +/- 0.5	2.06 +/- 0.17
	Shoal B Reference	136.51 +/- 61.54	13 +/- 2	2.73 +/- 0.12
	Shoal D	22.19 +/- 0.74	9 +/- 0	2.71 +/- 0.09
	Shoal D Reference	118.25 +/- 50.23	8 +/- 2	1.43 +/- 0.22
	Weaver Shoal	98.39 +/- 18.5	9.5 +/- 0.5	1.54 +/- 0.16
	Weaver Reference	69.81 +/- 10.25	9 +/- 4	1.86 +/- 1.01
Winter 04	Fenwick Island Shoal	12.94 +/- 1.98	4 +/- 0	1.68 +/- 0.18
	Fenwick Reference	6.4 +/- 1.87	3 +/- 0	1.4 +/- 0.03
	Shoal B	18.01 +/- 7.57	4.5 +/- 1.5	1.76 +/- 0.65
	Shoal B Reference	16.1 +/- 2.74	5 +/- 0	1.8 +/- 0.07
	Shoal D	19.13 +/- 16.5	3 +/- 0	1.39 +/- 0.19
	Shoal D Reference	53.46 +/- 34.57	5 +/- 1	1.84 +/- 0.09
	Weaver Shoal	20.26 +/- 0.92	4 +/- 0	1.57 +/- 0.23
	Weaver Reference	18.49 +/- 0.54	4.5 +/- 0.5	1.33 +/- 0.54

Table 3-5. (Continued)

Season	Site	Mean Total CPUE	Mean Number of Species	Mean Shannon
Spring 04	Fenwick Island Shoal	63.65 +/- 34.01	9.5 +/- 0.5	2.15 +/- 0.46
	Fenwick Reference	62.63 +/- 10.94	10.5 +/- 0.5	2.77 +/- 0.04
	Shoal B	18.89 +/- 13.13	5 +/- 1	1.93 +/- 0.01
	Shoal B Reference	44.35 +/- 1.51	11.5 +/- 0.5	3.01 +/- 0.2
	Shoal D	70.1 +/- 7.69	12 +/- 1	2.83 +/- 0.16
	Shoal D Reference	50.39 +/- 41.56	6.5 +/- 3.5	1.5 +/- 0.58
	Weaver Shoal	80.44 +/- 40.71	9 +/- 1	2.29 +/- 0.15
	Weaver Reference	23.36 +/- 19.21	6 +/- 4	1.52 +/- 0.52
Summer 04	Fenwick Island Shoal	83.29 +/- 36.33	8 +/- 1	1.02 +/- 0.19
	Fenwick Reference	157.2 +/- 71.07	11.5 +/- 1.5	2.46 +/- 0.26
	Shoal B	27.67 +/- 5.71	8 +/- 1	2.52 +/- 0.2
	Shoal B Reference	223.46 +/- 123.42	11 +/- 4	1.86 +/- 1.39
	Shoal D	46.11 +/- 33.37	7 +/- 1	2.05 +/- 0.02
	Shoal D Reference	149.93 +/- 113.08	9 +/- 1	2.26 +/- 0.45
	Weaver Shoal	129.45 +/- 20.01	10.5 +/- 2.5	1.74 +/- 0.04
	Weaver Reference	16.29 +/- 2.79	2 +/- 1	0.25 +/- 0.25





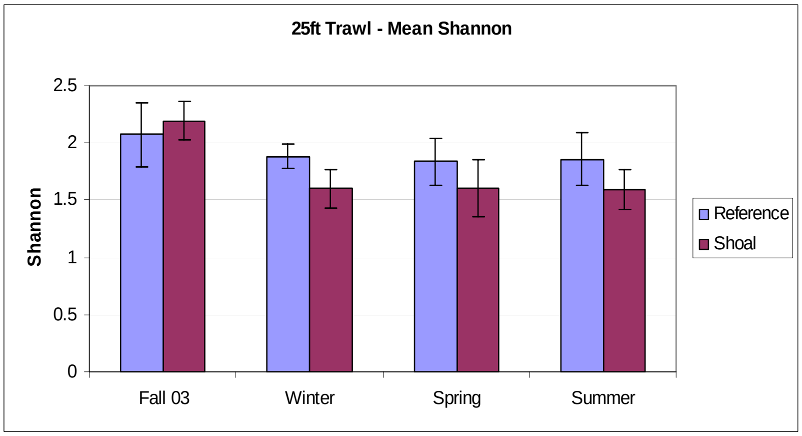


Figure 3-1. Combined two-year seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in small trawls at four shoal and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.

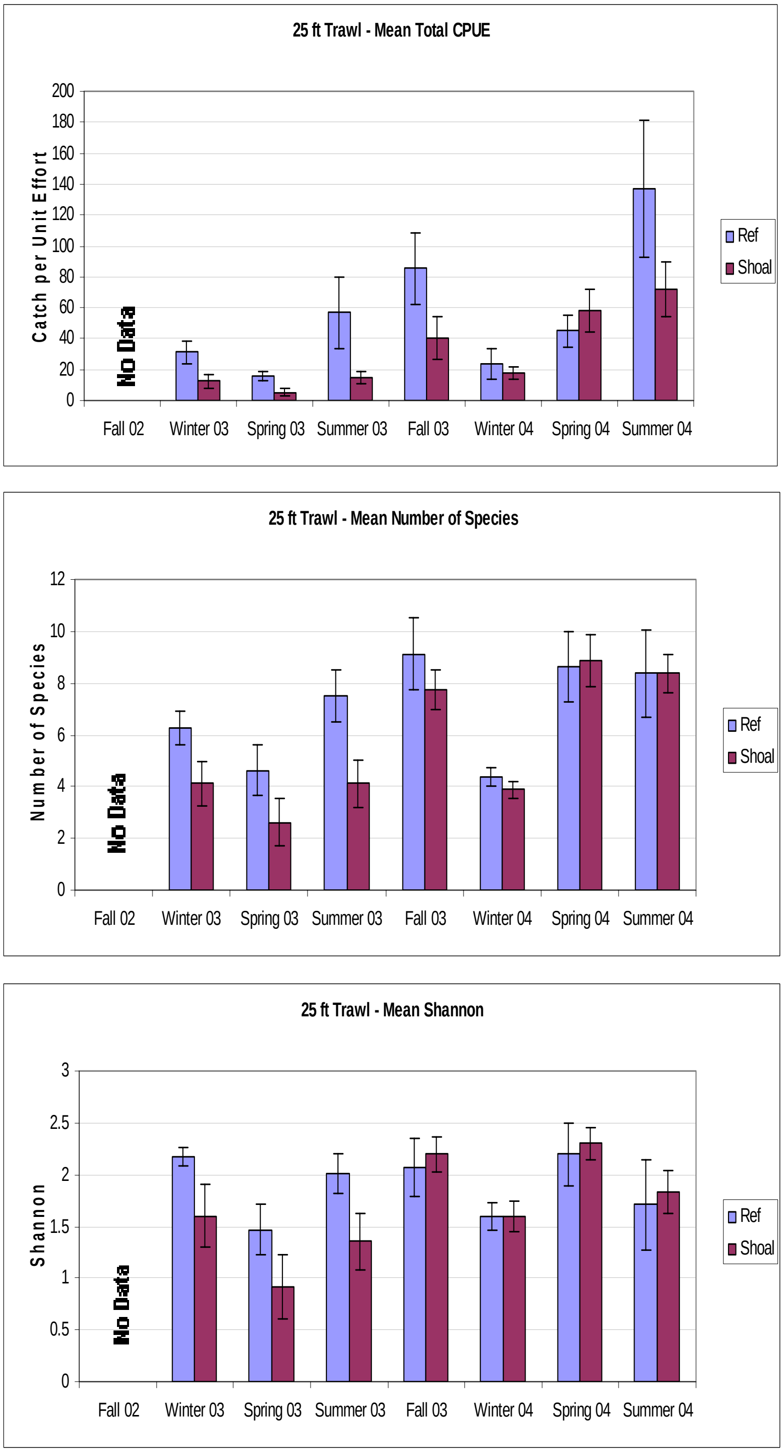
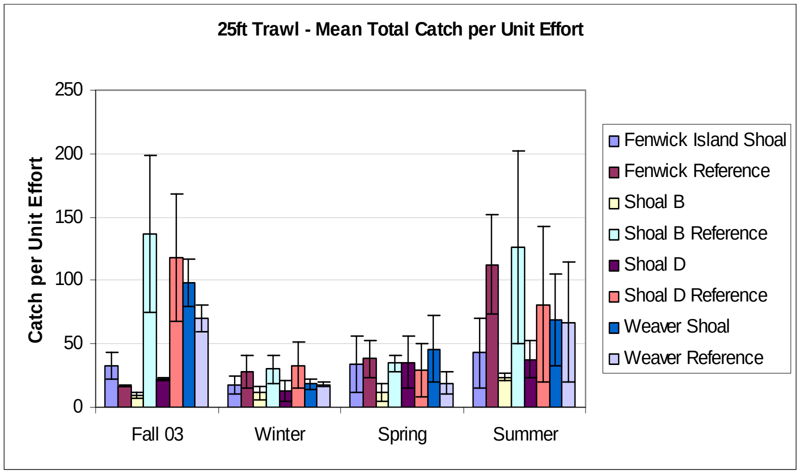
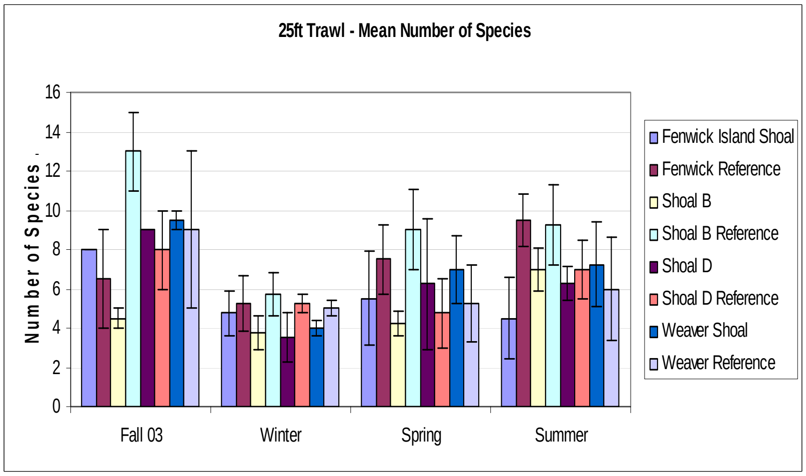


Figure 3-2. Seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in commercial trawls at four shoal and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.





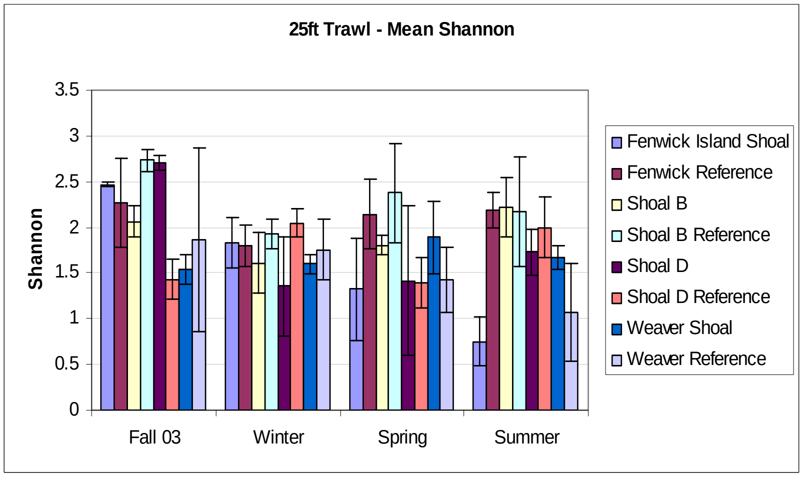
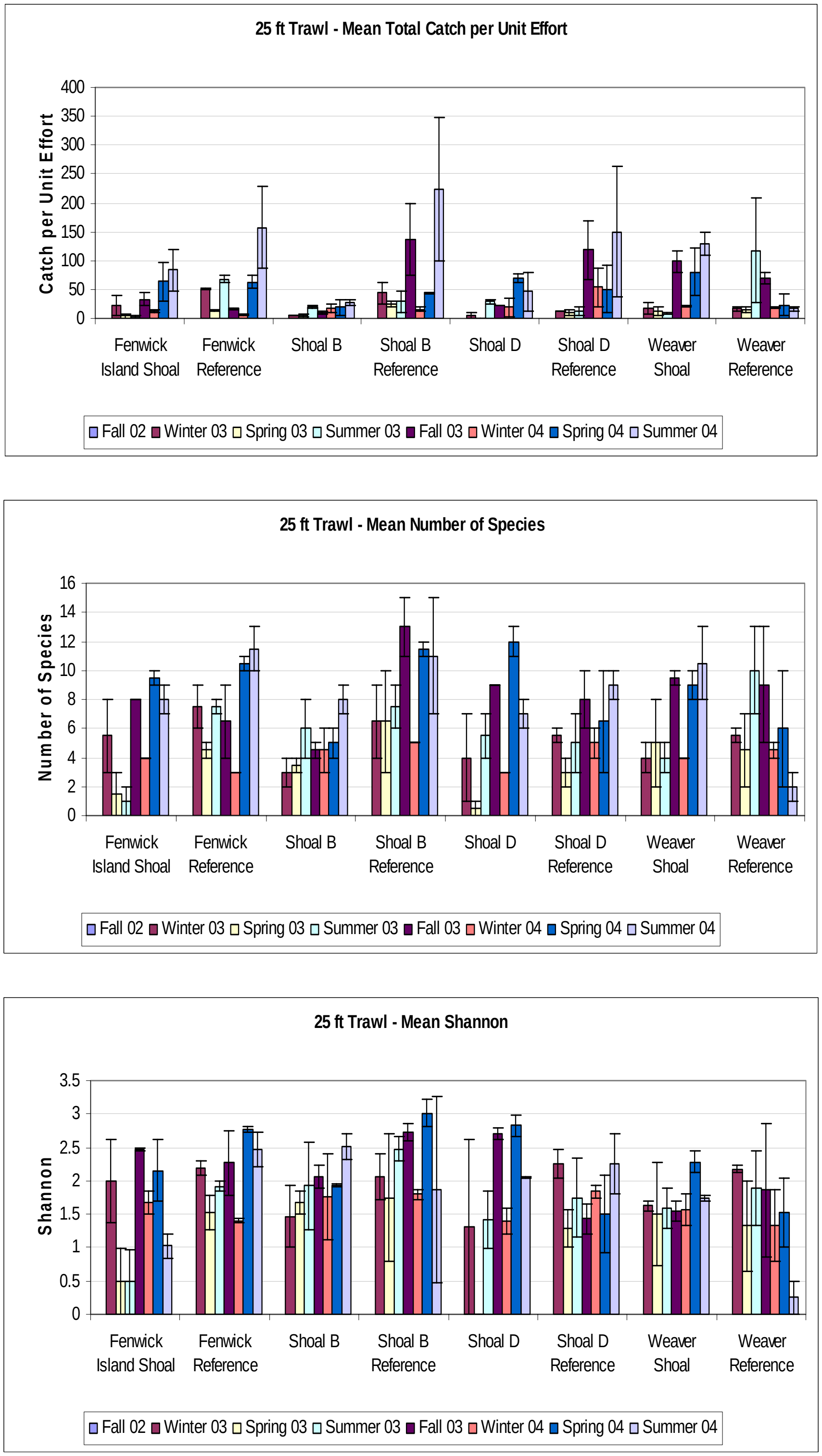


Figure 3-3. Combined two-year seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in small trawls at eight sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.


25 ft Trawl - Mean Total Catch per Unit Effort

25 ft Trawl - Mean Number of Species

25 ft Trawl - Mean Shannon

Figure 3-4. Seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in small trawls at eight sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.

3.1.2.2 Commercial Trawls

Commercial trawls were used to characterize the community of larger epibenthic and pelagic individuals present at the shoals and reference sites. Overall, total abundance from commercial trawl collections was mixed between shoals and reference sites, but mean total species richness and species diversity were higher at the reference sites when compared to the shoals (Table 3-6 and 3-7; Figure 3-5 and 3-6). When significant differences in abundance, richness, or diversity were detected, it generally favored higher measured values at the reference sites; however, occasionally the study some of the shoals exhibited higher abundance, richness, and diversity when compared to their paired reference site (Tables 3-8 and 3-9; Figure 3-7 and 3-8).

A total of 56 different species of fish and invertebrates were collected in the commercial trawls on shoals and reference sites (Table C-1). Overall total species richness was highest at the reference sites during each season (Table 3-6 and 3-7). The total number of species collected in the commercial trawls was much higher at the reference sites as opposed to the shoals (Table C-1). Forty-one fish and 12 invertebrates were collected at the reference sites and 31 fish and 11 invertebrates were collected at the shoals. Twelve fish and one invertebrate species collected at the reference sites were not collected at the shoals, and only three species, the blue crab, harvestfish, and Spanish mackerel were found only on the shoals.

Scup and winter skate were the most abundant organisms over the two-year study, comprising 19% and 13% of the total collection, respectively. Windowpane flounder and winter skate were the most prevalent species, collected in every season at nearly every site (Table C-7). Among the invertebrate species collected, squid and lady crabs were the most abundant over all the sites during the two-years (Table C-1; Figure C-1). In addition, squid were also the most commonly collected invertebrate species present throughout the sites in every season, but winter (Table C-7).

Fall

In the fall season, catch per unit of effort was mixed between shoal and the reference sites (Table 3-8; Figure 3-6). Both Fenwick Island (437.25±280.08 SE) and Weaver (271.74±68.51 SE) shoal were higher in abundance when compared to their paired reference sites (240.93±43.02 SE and 220.71±10.25 SE respectively). Conversely, Shoal D and B exhibited lower abundance than their reference sites and differences between Shoal B and its reference were significant (Table 3-8).

Total species richness and species diversity followed a similar pattern in the fall with higher richness and diversities at all reference sites but Shoal D Reference (Table 3-8). Shoal B exhibited the lowest total species richness overall, and the differences between Shoal B (9±2.12 SE) and its paired reference site (16.75±1.89 SE) were significant. Species diversity was highest on Weaver Shoal Reference and lowest on Shoal D Reference. Significant differences in species diversity were also detected between Weaver Shoal and Weaver Shoal Reference (Table 3-8).

A total of 24 fish and 13 invertebrate species were collected throughout the sites in the fall. Fish were more abundant than invertebrates accounting for 89% of the total catch in the fall collections and invertebrates accounted for 11% (Figure C-1). More fish species were found at the reference sites than at the shoals, with 23 fish at the reference sites compared to only 14 at the shoals. Invertebrate numbers were equal between references and shoal with eleven species of invertebrate on shoals and reference sites. Of the 37 species collected in the fall by the commercial trawl, 10 fish and 2 invertebrates occurred only at reference sites and only three species, the blue crab, moon snails, and Spanish mackerel were found only at the shoals (Table C-1).

Spiny dogfish and winter skate were the most abundant fish species and most common fish collected throughout the fall (Table C-7 and C-8; Figure C-1). Both species were collected at every site and accounted for over 50% of the total catch combined and 57% of total fish abundance in the fall. Spiny dogfish comprised 21% of the total catch on shoals, and 38% of the reference sites catch. Winter skate was less abundant than spiny dogfish, but represented 25% of the shoal catch and 18% of the reference catches. Striped bass were collected in limited numbers in the fall, however that species accounted for 31% of the total shoal catch due to one large collection at Fenwick Shoal (1,225 in one tow in fall of 2003). Other fish species collected in the fall were little skate, clearnose skate, summer flounder, and windowpane flounder.

Starfish and lady crabs were the most abundant invertebrate species in the fall collections accounting for 7% of the total abundance combined (Table C-7 and C-8; Figure C-1). Starfish comprised 56% of the total invertebrate abundance on the shoals and 27% at the reference sites. Lady crabs accounted for 25% of invertebrates found on the shoals and 31% of invertebrates at the reference sites. Other invertebrate species collected in the fall were squid, horseshoe crab, channeled whelk, and Atlantic rock crab.

Winter

Overall, total abundance in the winter sampling was lower than that of any other season (Table 3-6 and 3-8). Total abundance was higher at all reference sites for all paired sites with significant differences detected between Fenwick Shoal, shoal D, and their reference sites (Table 3-8; Figure 3-6). The reference site for Shoal B exhibited the highest abundance (31.86±11.96 SE) and Weaver Shoal had the lowest (8.33±4.33 SE).

Similar to total abundance, overall total species richness was also the lowest compared to all other seasons (Table 3-6 and 3-8). Total species richness was highest at all the reference sites except Shoal D Reference, which had equal numbers of species as Shoal D in the winter. When compared to the reference sites species diversity followed the same pattern as total species richness with lower diversity on all shoals except Shoal D (Table 3-8). The highest diversity was found on Shoal B Reference and the lowest was found on Shoal B.

A total of 17 fish and 4 invertebrate species were collected throughout the sites in the winter sampling (Table C-1). Altogether fish were much more abundant than invertebrates accounting for 93% of the total catch in the winter collections (Table C-2; Figure C-1). A total of 13 fish species were collected at the reference sites compared to 14 collected at the shoals. Invertebrate numbers were similar between references and shoal with only two species present at the reference sites and 4 on the shoals. Of the 21 species collected in the winter, 4 fish and 2 invertebrates occurred only at the shoals and just four fish, the Atlantic menhaden, clearnose skate, hickory shad, and spotted hake were found only at reference sites (Table C-1).

Three fish species, the winter skate, windowpane flounder, and little skate dominated the winter collections (Figure C-1). Together these three species accounted for 60% of the entire total abundance in the winter. Little skate and windowpane flounder were collected at every site and winter skate was collected at every site but Weaver Shoal (Table C-7). Between them, winter skate exhibited the highest abundance and was more abundant at the reference sites than at the shoals (Table C-2; Figure C-1). Winter skate accounted for 25% of the total catch and 27% of total fish abundance. The little skate was more abundant at the shoals accounting for 19% of total catch and 22% of the total fish catch at the shoals. Windowpane was found to be equally abundant on shoals and reference sites (Table C-2 and C-8). Other fish species collected in the winter were little skate, clearnose skate, summer flounder, and windowpane flounder.

Invertebrates accounted for only 7% of the entire collection over all the sites in the winter. Starfish and horseshoe crabs were the most abundant invertebrate species in the winter collections accounting for just 7% of the total species abundance combined (Table C-2; Figure C-1). Starfish were collected at every site but Shoal B and accounted for 60% of the total invertebrate abundance on the shoals and 44% at the reference sites. Horseshoe crabs were collected at every site but Shoal D Reference and Weaver Shoal, and accounted for 22% of invertebrates found on the shoals and 56% of invertebrates at the reference sites. Two other invertebrates were also collected in winter, moon snails and Atlantic rock crab. These species were in very low abundance and were collected only at shoal sites (Table C-1 and C-2).

Spring

In the spring, total abundances were higher overall compared to any other season with catch per unit of effort generally higher on the shoals than at reference sites (Table 3-8; Figure 3-6). Fenwick Island Shoal (1807.44±1106.40 SE) exhibited the highest abundance for shoals and Weaver Shoal Reference (1328.73±719.38 SE) had the highest total abundance for paired reference sites. Shoal B and Shoal B Reference had the lowest abundances in the spring. No significant differences in abundance were detected between shoals and the paired reference sites in the spring (Table 3-8).

Total species richness and species diversity were much higher in the spring compared to winter (Table 3 -6). Total species richness was highest at all the reference sites except Shoal D Reference, which had an average total species richness of 9 species compared to Shoal D where 12 species were collected in the spring (Table 3-8). Significant differences in total species richness were detected between Fenwick Island Shoal (8.5±0.29 SE) and Fenwick Island

Reference (14±1.22 SE). Species diversity was highest at Shoal B Reference (2.49±0.12 SE) and the lowest was found on Shoal D Reference (1.04±0.34 SE).

A total of 23 fish and 8 invertebrate species collected in the spring catch (Table C-1). Altogether fish were more abundant than invertebrates accounting for 90% of the total catch in the winter collections (Table C-2; Figure C-2). More fish species were collected at the reference sites than at the shoals, with 21 species at the reference sites compared to 17 species collected at the shoals. Total invertebrate species was also higher at reference sites (8) than at shoals (5). Of the 31 species collected in the spring, 6 fish and 2 invertebrates occurred only at reference sites and only two fish species, bluefish and Spanish mackerel were found only at the shoals (Table C-1).

Scup and butterfish were the most abundant fishes and the two most common species collected in the spring (Table C-7 and C-8; Figure C-2). Altogether these two species accounted for over 75% of the total catch in the spring. Both scup and butterfish were collected at every site and accounted for 87% of the total fish abundance (Table C-7 and C-8; Figure C-2). Scup was more abundant at shoals than at reference sites accounting for over 65% of the total catch and 73% of the total fish catch at shoal sites. Conversely, butterfish were more abundant at reference sites accounting for 61% of the catch and 68% of the total fish abundance at the reference sites. Other fish species collected in the spring were smooth dogfish, little skate, northern searobin, and winter skate (Table C-1).

In the spring, invertebrates were more abundant than in winter, accounted for 10% of the entire collection. Squid was the most dominate invertebrate collected and was present at all sites in the spring (Table C-7 and C-8; Figure C-2). This species accounted for 9% of the total catch and 92% of all invertebrates on shoals and reference sites. Starfish were also collected in the spring and were found on both shoals and reference sites (Table C-7 and C-8). Six other invertebrate species were collected in the spring; among them were portly spider crab, knobbed and channeled whelk, and horseshoe crabs (Table C-1).

Summer

In the summer, catch per unit of effort was mixed between shoal and the reference sites. Both Shoal D (163.83±78.31 SE) and Weaver (808.14±694.09 SE) shoal were higher in total abundance when compared to their paired reference sites (128.25±24.40 SE and 169.54±48.25 SE respectively). Conversely, Fenwick Island Shoal and Shoal B exhibited lower abundances than their reference sites (Table C-1). Weaver Shoal had the highest abundance overall and Shoal B had the lowest. No significant differences in total abundance were detected between shoal and paired reference sites (Table 3-8).

Total species richness was higher at all reference sites when compared to the shoals (Table 3-8). Fenwick Island Shoal reference (12±0.71 SE) exhibited significantly higher abundance when compared to Fenwick Island Shoal (6.75±0.75). Species diversity was also higher at the reference sites compared to the shoals (Table 3-8). The highest diversity was found on Fenwick Island Shoal Reference and the lowest was found on Shoal B.

The total number of species collected in the summer was second only to the fall collections, with a total of 26 fish and 10 invertebrate species collected throughout the sites. Like all other seasons in the commercial catch, fish were more abundant than invertebrates accounting for 84% of the total catch in the summer collections (Table C-2; Figure C-2). More fish species were collected at the reference sites than at the shoals, with 25 species at the reference sites compared to only 18 species collected at the shoals. Total numbers of invertebrate species at shoals and at the reference sites also differed, with a total of 9 invertebrates at the reference sites and 7 at the shoals. Of the 36 species collected in the summer, 8 fish and 3 invertebrates occurred only at reference sites and only harvest fish and portly spider crab were found only at the shoals (Table C-1).

Scup and northern searobin were the two most abundant fish species collected in the summer (Table C-8; Figure C-2). Although present at only four sites, scup still dominated the summer collection accounting for 32% of the total catch. Scup was more abundant at shoals than at reference sites accounting for over 56% of the total catch and 68% of the total fish catch at shoal sites. Conversely northern searobin was more abundant at reference sites accounting for 36% of the total catch and 42% of the total fish catch at the reference sites. Other fish species collected in the summer were clearnose skate, summer flounder, windowpane flounder, and a thresher shark (Table C-1).

In the commercial trawls, invertebrates accounted for 16% of the entire collection over all the sites in the summer. Invertebrates were more abundant and more common in the summer than any other season (Table C-1 and C-2). Lady crabs and squid were the most abundant invertebrate species in the summer collections accounting for 20% of the total species abundance combined (Table C-2 and C-3). Lady crabs comprised 65% of the total invertebrate abundance on the shoals and 26% at the reference sites (Figure C-3). Squid accounted for 12% of invertebrates found on the shoals and 66% of invertebrates at the reference sites. Other invertebrate species collected in the fall were starfish, coarse hand lady crabs, horseshoe crab, and Atlantic rock crab (Table C-1).

Table 3-6. Combined two-year seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in commercial trawls at four shoal and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004. Significant differences between shoal and reference sites from ANOVA tests are highlighted.

Season	Site	Mean Total CPUE	Mean Number of Spp	Mean Shannon
Fall	Ref	248.32 +/- 30.36	14.81 +/- 1.07	2.47 +/- 0.16
	Shoal	258.28 +/- 72.03	11.44 +/- 0.82	2.04 +/- 0.13
Winter	Ref	25.98 +/- 3.42	5.5 +/- 0.52	1.93 +/- 0.12
	Shoal	11.73 +/- 2.29	3.81 +/- 0.47	1.49 +/- 0.2
Spring	Ref	612.08 +/- 202.12	11.38 +/- 0.9	1.75 +/- 0.26
	Shoal	735.7 +/- 311.31	10 +/- 0.55	1.9 +/- 0.24
Summer	Ref	253.9 +/- 62.11	9.88 +/- 0.71	1.85 +/- 0.15
	Shoal	306.2 +/- 174.49	6.5 +/- 0.52	1.41 +/- 0.13

* Highlighted denotes significant difference (alpha = 0.05)

Table 3-7. Seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in commercial trawls at four shoal and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004. Significant differences between shoal and reference sites from ANOVA tests are highlighted.

Season	Site	Mean Total CPUE	Mean Number of Species	Mean Shannon
Fall 02	Ref	166.02 +/- 22.57	14.75 +/- 1.86	2.76 +/- 0.23
	Shoal	135.28 +/- 17.64	11 +/- 1.55	2.14 +/- 0.18
Winter 03	Ref	30.33 +/- 6.1	6.63 +/- 0.8	2.32 +/- 0.08
	Shoal	17.53 +/- 3.15	4.75 +/- 0.45	1.79 +/- 0.13
Spring 03	Ref	263.27 +/- 75.68	12.38 +/- 1.41	2.07 +/- 0.43
	Shoal	110.46 +/- 17.3	11.25 +/- 0.75	2.7 +/- 0.1
Summer 03	Ref	171.84 +/- 67.75	10.25 +/- 0.88	2.21 +/- 0.22
	Shoal	571.55 +/- 332.12	7.88 +/- 0.44	1.29 +/- 0.21
Fall 03	Ref	330.61 +/- 38.8	14.88 +/- 1.2	2.18 +/- 0.2
	Shoal	381.28 +/- 132.66	11.88 +/- 0.64	1.93 +/- 0.2
Winter 04	Ref	21.62 +/- 2.76	4.38 +/- 0.42	1.55 +/- 0.11
	Shoal	5.94 +/- 1.72	2.88 +/- 0.69	1.19 +/- 0.35
Spring 04	Ref	960.89 +/- 366.87	10.38 +/- 1.08	1.44 +/- 0.26
	Shoal	1360.94 +/- 550.78	8.75 +/- 0.53	1.11 +/- 0.24
Summer 04	Ref	335.96 +/- 100.08	9.5 +/- 1.15	1.49 +/- 0.12
	Shoal	40.86 +/- 8.15	5.13 +/- 0.64	1.53 +/- 0.15

Table 3-8. Combined two-year seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in commercial trawls at eight sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004. Significant differences between paired sites from ANOVA tests are highlighted.

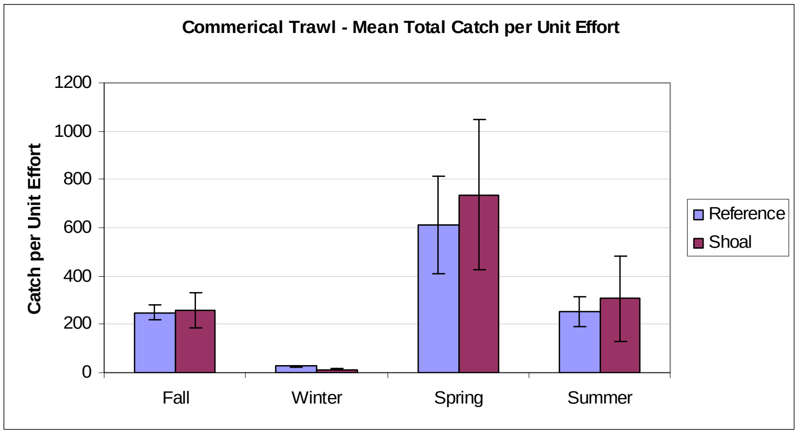
Season	Site	Mean Total CPUE	Mean Number of Spp	Mean Shannon
Fall	Fenwick Island Shoal	437.25 +/- 280.08	11.75 +/- 1.38	1.98 +/- 0.42
	Fenwick Reference	240.93 +/- 43.02	15.5 +/- 0.87	2.44 +/- 0.23
	Shoal B	119.16 +/- 39.6	9 +/- 2.12	1.82 +/- 0.21
	Shoal B Reference	308.75 +/- 75.53	16.75 +/- 1.89	2.72 +/- 0.45
	Shoal D	204.96 +/- 30.24	10.5 +/- 0.87	1.84 +/- 0.1
	Shoal D Reference	222.87 +/- 90.3	9.5 +/- 2.06	1.79 +/- 0.1
	Weaver Shoal	271.74 +/- 68.51	14.5 +/- 0.87	2.51 +/- 0.07
	Weaver Reference	220.71 +/- 31.91	17.5 +/- 1.04	2.93 +/- 0.14
Winter	Fenwick Island Shoal	10.5 +/- 3.06	4.25 +/- 0.63	1.86 +/- 0.19
	Fenwick Reference	29.99 +/- 6.11	6.25 +/- 1.31	1.94 +/- 0.26
	Shoal B	16.25 +/- 7.94	3.25 +/- 1.31	0.78 +/- 0.45
	Shoal B Reference	31.86 +/- 11.96	6.25 +/- 1.31	2.06 +/- 0.25
	Shoal D	11.85 +/- 1.59	4.75 +/- 0.63	1.98 +/- 0.21
	Shoal D Reference	24.37 +/- 1.44	4.75 +/- 0.25	1.9 +/- 0.11
	Weaver Shoal	8.33 +/- 4.33	3 +/- 1.08	1.35 +/- 0.46
	Weaver Reference	17.69 +/- 3.37	4.75 +/- 1.11	1.85 +/- 0.37
Spring	Fenwick Island Shoal	1807.44 +/- 1106.4	8.5 +/- 0.29	1.46 +/- 0.59
	Fenwick Reference	563.94 +/- 166.06	14 +/- 1.22	1.55 +/- 0.08
	Shoal B	138.68 +/- 41.73	9 +/- 0.82	2 +/- 0.42
	Shoal B Reference	113.08 +/- 30.29	10.25 +/- 0.25	2.49 +/- 0.12
	Shoal D	594.3 +/- 338.6	12.25 +/- 1.18	2.01 +/- 0.62
	Shoal D Reference	442.56 +/- 80.67	9.25 +/- 1.25	1.04 +/- 0.34
	Weaver Shoal	402.38 +/- 229	10.25 +/- 1.03	2.14 +/- 0.39
	Weaver Reference	1328.73 +/- 719.38	12 +/- 2.94	1.94 +/- 0.9
Summer	Fenwick Island Shoal	152.15 +/- 72.69	6.75 +/- 0.75	1.71 +/- 0.13
	Fenwick Reference	412.44 +/- 196.82	12 +/- 0.71	1.99 +/- 0.38
	Shoal B	100.68 +/- 54.99	5.5 +/- 1.76	1.1 +/- 0.1
	Shoal B Reference	305.36 +/- 136.32	11 +/- 1.68	1.91 +/- 0.44
	Shoal D	163.83 +/- 78.31	6 +/- 0.41	1.21 +/- 0.22
	Shoal D Reference	128.25 +/- 24.4	6.75 +/- 0.48	1.7 +/- 0.19
	Weaver Shoal	808.14 +/- 694.09	7.75 +/- 0.75	1.6 +/- 0.42
	Weaver Reference	169.54 +/- 48.25	9.75 +/- 1.11	1.82 +/- 0.28

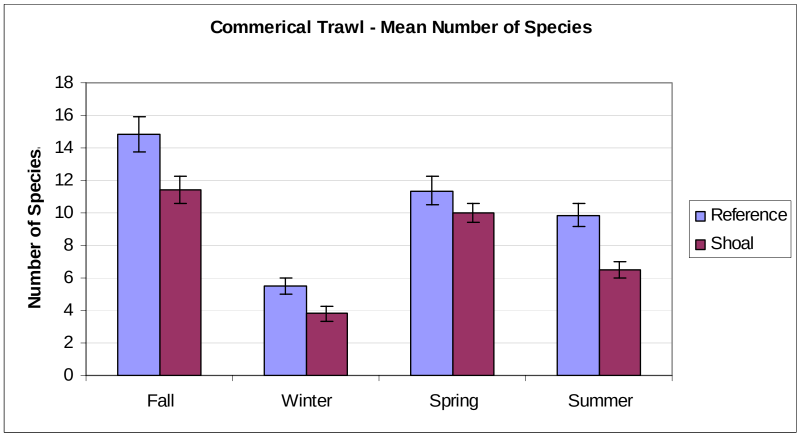
Table 3-9. Seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in commercial trawls at eight sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004. Significant differences between paired sites from ANOVA tests are highlighted.

Season	Site	Mean Total CPUE	Mean Number of Species	Mean Shannon
Fall 02	Fenwick Island Shoal	169.32 +/- 13.17	14 +/- 1	2.5 +/- 0.02
	Fenwick Reference	188.09 +/- 40.98	16.5 +/- 1.5	2.76 +/- 0.29
	Shoal B	62.35 +/- 5.55	5.5 +/- 1.5	1.56 +/- 0.28
	Shoal B Reference	221.15 +/- 30.74	19.5 +/- 1.5	3.46 +/- 0.09
	Shoal D	153.14 +/- 10.68	9.5 +/- 1.5	1.88 +/- 0.16
	Shoal D Reference	83.67 +/- 14.8	7 +/- 2	1.89 +/- 0.1
	Weaver Shoal	156.3 +/- 34.04	15 +/- 2	2.62 +/- 0.04
	Weaver Reference	171.18 +/- 33.04	16 +/- 1	2.94 +/- 0.19
Spring 03	Fenwick Island Shoal	86.46 +/- 12.09	9 +/- 0	2.48 +/- 0.05
	Fenwick Reference	298.82 +/- 42.46	13.5 +/- 2.5	1.64 +/- 0.08
	Shoal B	79.83 +/- 5.08	10 +/- 1	2.64 +/- 0.13
	Shoal B Reference	61.09 +/- 7.94	10 +/- 0	2.66 +/- 0.11
	Shoal D	117.72 +/- 14.68	14 +/- 0	3.08 +/- 0.1
	Shoal D Reference	557.38 +/- 112.58	9 +/- 3	0.48 +/- 0.22
	Weaver Shoal	157.84 +/- 64.67	12 +/- 0	2.61 +/- 0.17
	Weaver Reference	135.79 +/- 30.27	17 +/- 1	3.49 +/- 0.03
Summer 03	Fenwick Island Shoal	266.76 +/- 73.16	8 +/- 0	1.9 +/- 0.03
	Fenwick Reference	79.94 +/- 21.8	11 +/- 1	2.63 +/- 0.18
	Shoal B	186.79 +/- 57.55	8.5 +/- 0.5	1.02 +/- 0.13
	Shoal B Reference	358.67 +/- 274.86	13 +/- 0	2.51 +/- 0.49
	Shoal D	255.63 +/- 140.82	6 +/- 0	1.14 +/- 0.53
	Shoal D Reference	109.93 +/- 3.69	7 +/- 1	1.61 +/- 0.44
	Weaver Shoal	1577 +/- 1307.01	9 +/- 0	1.07 +/- 0.67
	Weaver Reference	138.82 +/- 65.02	10 +/- 1	2.1 +/- 0.53
Winter 03	Fenwick Island Shoal	14.08 +/- 5.54	4.5 +/- 1.5	1.86 +/- 0.45
	Fenwick Reference	30.94 +/- 14.65	7.5 +/- 2.5	2.34 +/- 0.26
	Shoal B	29.92 +/- 1.7	5.5 +/- 0.5	1.57 +/- 0.09
	Shoal B Reference	46.12 +/- 20.99	8 +/- 2	2.46 +/- 0.05
	Shoal D	10.97 +/- 3.57	4.5 +/- 1.5	1.83 +/- 0.45
	Shoal D Reference	22.47 +/- 1.34	4.5 +/- 0.5	2.08 +/- 0.09
	Weaver Shoal	15.14 +/- 4.15	4.5 +/- 0.5	1.9 +/- 0.07
	Weaver Reference	21.8 +/- 0.27	6.5 +/- 0.5	2.4 +/- 0.18
Fall 03	Fenwick Island Shoal	705.18 +/- 571.78	9.5 +/- 0.5	1.46 +/- 0.72
	Fenwick Reference	293.77 +/- 61.97	14.5 +/- 0.5	2.12 +/- 0.2
	Shoal B	175.97 +/- 54.05	12.5 +/- 0.5	2.08 +/- 0.25
	Shoal B Reference	396.36 +/- 133.92	14 +/- 2	1.98 +/- 0.3
	Shoal D	256.78 +/- 0.54	11.5 +/- 0.5	1.8 +/- 0.17
	Shoal D Reference	362.07 +/- 99.79	12 +/- 3	1.7 +/- 0.17
	Weaver Shoal	387.17 +/- 18.71	14 +/- 0	2.39 +/- 0.04
	Weaver Reference	270.25 +/- 10.56	19 +/- 1	2.92 +/- 0.28

Table 3-9. (Continued)

Season	Site	Mean Total CPUE	Mean Number of Species	Mean Shannon
Spring 04	Fenwick Island Shoal	3528.43 +/- 1192.02	8 +/- 0	0.44 +/- 0.13
	Fenwick Reference	829.06 +/- 151.89	14.5 +/- 1.5	1.46 +/- 0.13
	Shoal B	197.54 +/- 59.13	8 +/- 1	1.36 +/- 0.45
	Shoal B Reference	165.07 +/- 6.03	10.5 +/- 0.5	2.32 +/- 0.14
	Shoal D	1070.88 +/- 483.12	10.5 +/- 1.5	0.95 +/- 0.26
	Shoal D Reference	327.74 +/- 1.87	9.5 +/- 0.5	1.6 +/- 0.13
	Weaver Shoal	646.92 +/- 436.88	8.5 +/- 0.5	1.67 +/- 0.65
	Weaver Reference	2521.67 +/- 507.84	7 +/- 1	0.39 +/- 0.01
Summer 04	Fenwick Island Shoal	37.54 +/- 8.74	5.5 +/- 0.5	1.51 +/- 0.16
	Fenwick Reference	744.95 +/- 104.04	13 +/- 0	1.34 +/- 0.1
	Shoal B	14.58 +/- 1.87	2.5 +/- 0.5	1.17 +/- 0.18
	Shoal B Reference	252.05 +/- 173.99	9 +/- 3	1.3 +/- 0.43
	Shoal D	72.03 +/- 10.24	6 +/- 1	1.29 +/- 0.08
	Shoal D Reference	146.56 +/- 53.73	6.5 +/- 0.5	1.78 +/- 0.11
	Weaver Shoal	39.28 +/- 0.86	6.5 +/- 0.5	2.13 +/- 0.19
	Weaver Reference	200.26 +/- 88.61	9.5 +/- 2.5	1.53 +/- 0.18
Winter 04	Fenwick Island Shoal	6.92 +/- 0.03	4 +/- 0	1.86 +/- 0.06
	Fenwick Reference	29.04 +/- 2.72	5 +/- 1	1.54 +/- 0.12
	Shoal B	2.58 +/- 1.36	1 +/- 0	0 +/- 0
	Shoal B Reference	17.59 +/- 3.32	4.5 +/- 0.5	1.65 +/- 0.23
	Shoal D	12.73 +/- 0.97	5 +/- 0	2.12 +/- 0.08
	Shoal D Reference	26.27 +/- 1.87	5 +/- 0	1.72 +/- 0.06
	Weaver Shoal	1.51 +/- 1.51	1.5 +/- 1.5	0.79 +/- 0.79
	Weaver Reference	13.58 +/- 5.87	3 +/- 1	1.3 +/- 0.44





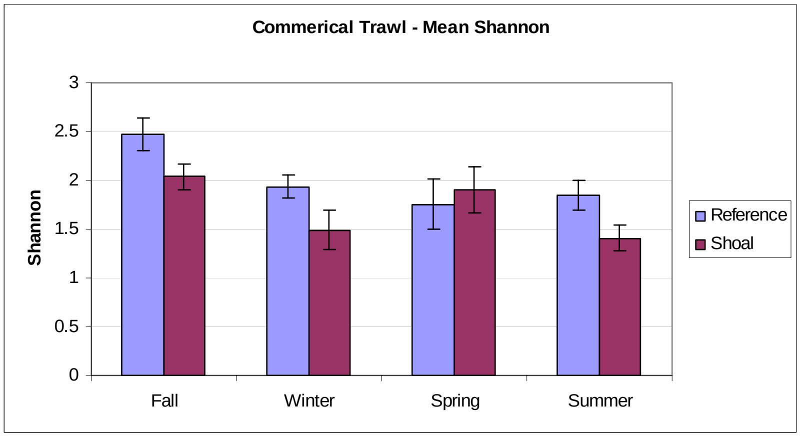


Figure 3-5. Combined two-year seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in commercial trawls at four shoal and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.

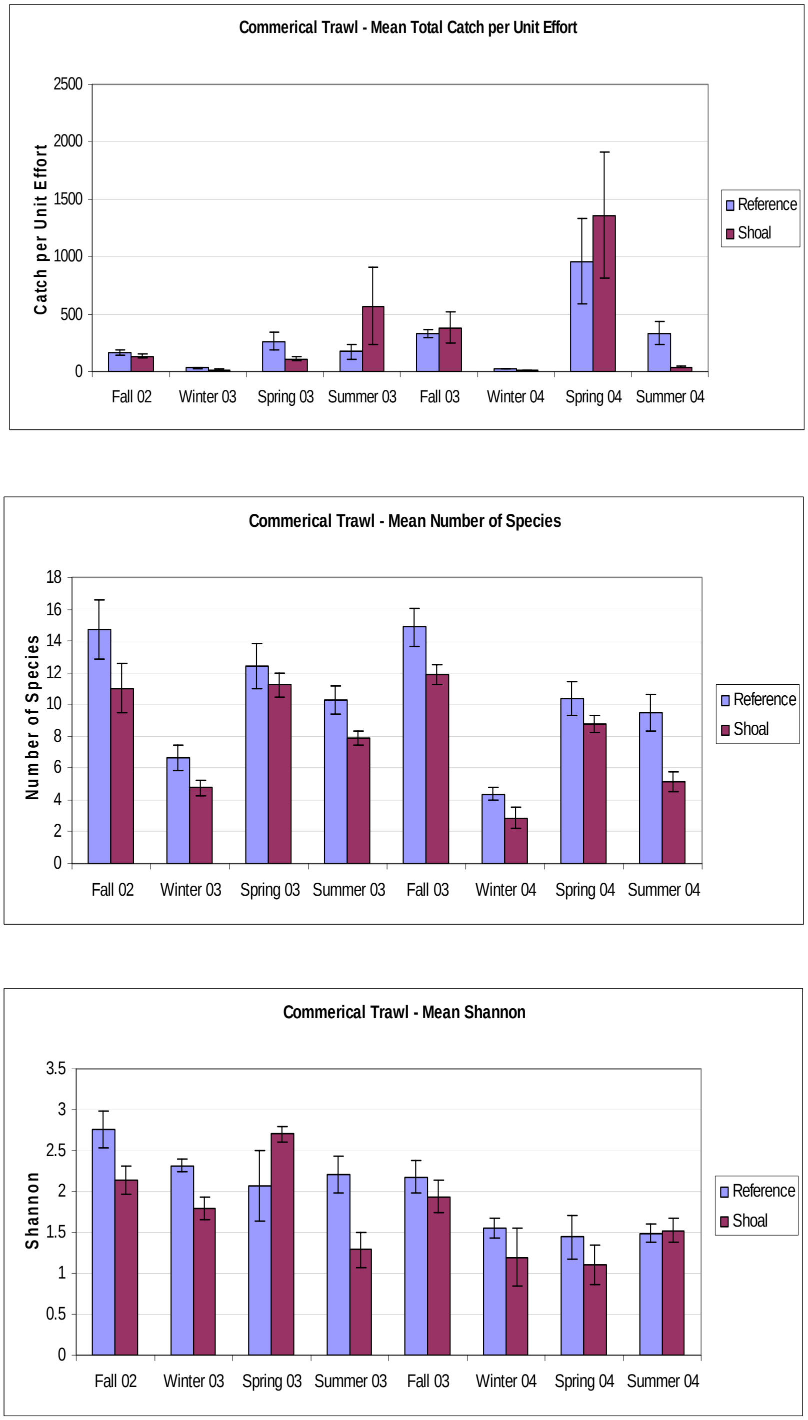


Figure 3-6. Seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in commercial trawls at four shoal and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.

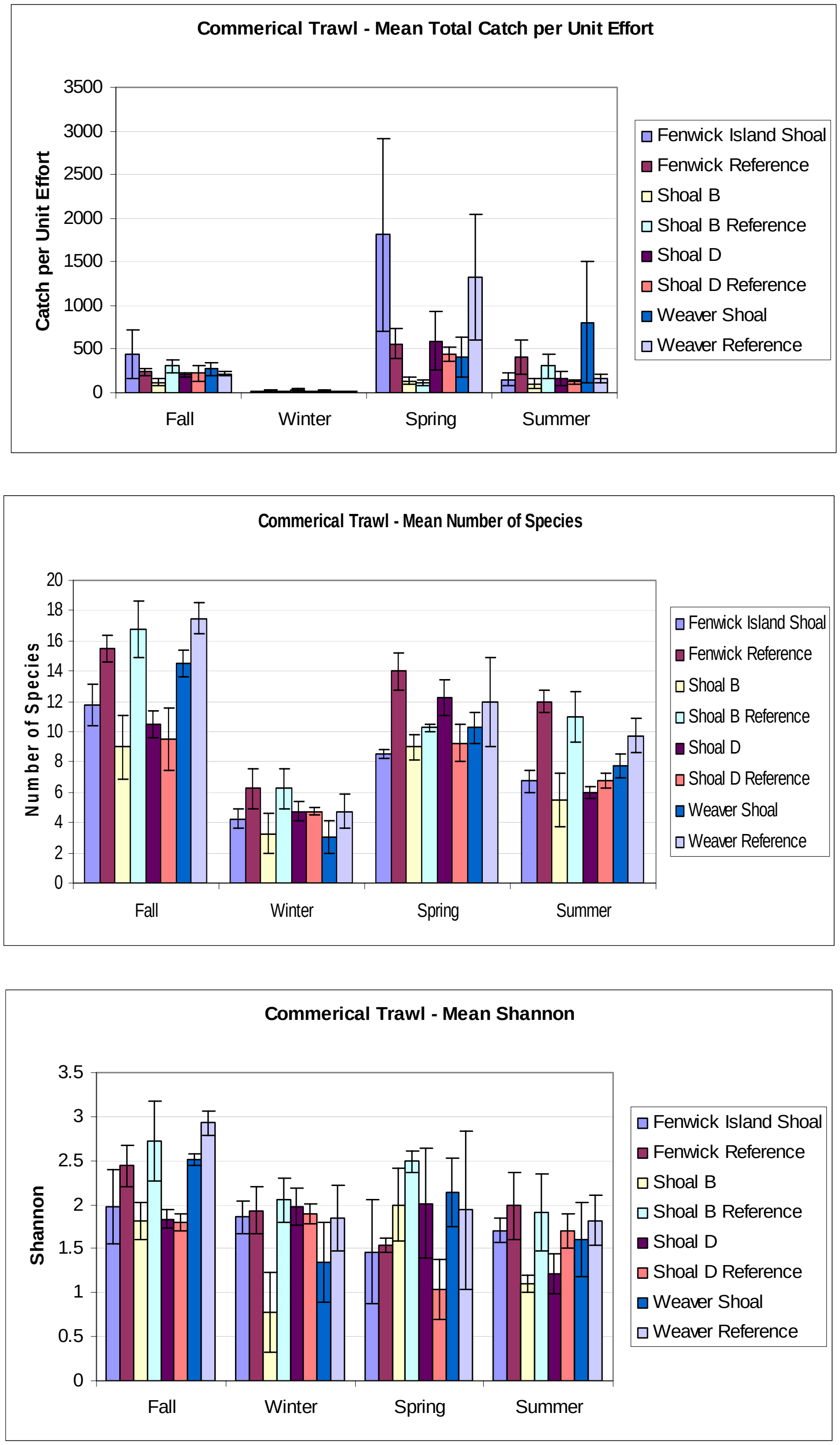
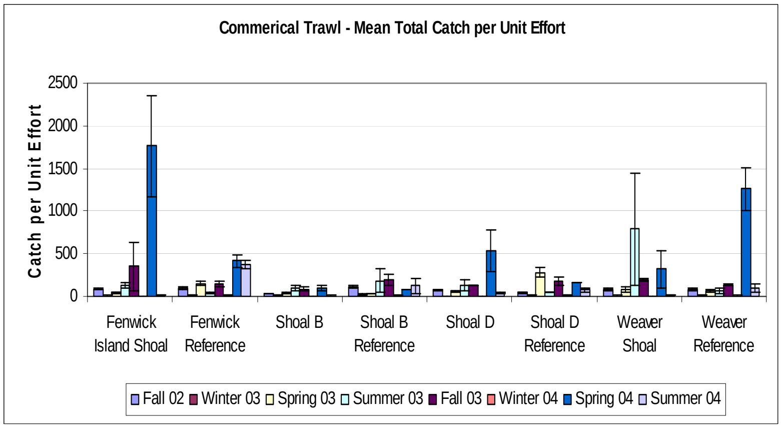
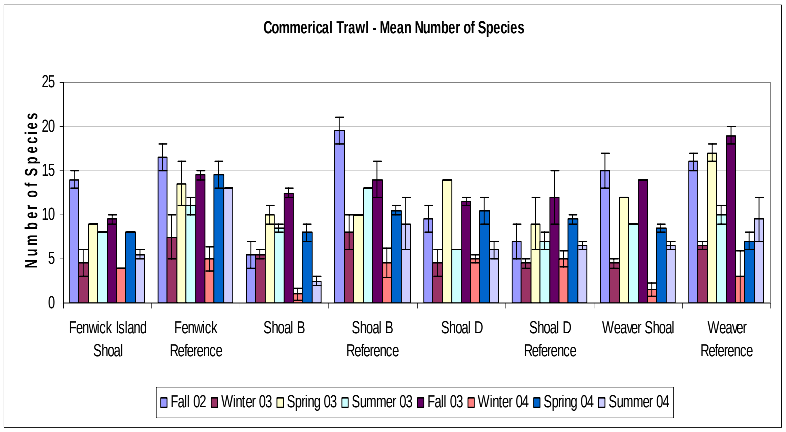


Figure 3-7. Combined two-year seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in commercial trawls at eight sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.





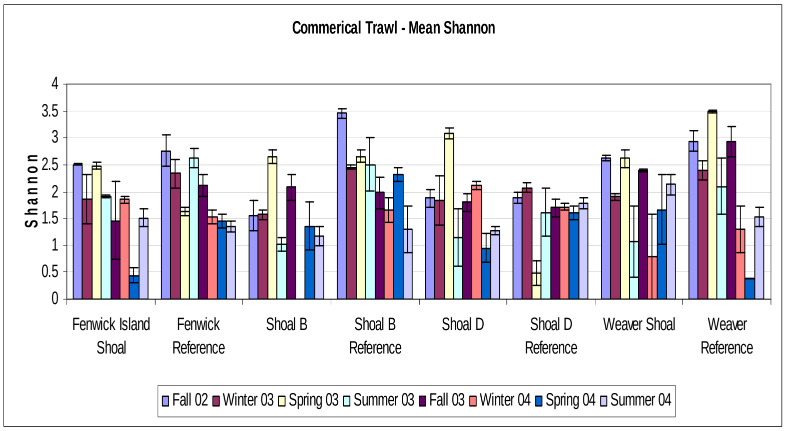


Figure 3-8. Seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in commercial trawls at eight sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.

3.1.2.3 Gillnets

Gill nets were used to characterize highly mobile benthic and pelagic species that were otherwise not susceptible to capture by the trawling gears. Overall, mean total abundance, mean total species richness, and species diversity did not differ greatly between reference sites and shoals with no obvious patterns (Table 3-10 and 3-11; Figure 3-9 and 3-10). There were two occasions where significant differences in abundance were detected between individual shoals and reference sites with split results, and very few significant differences were detected between individual shoals or reference sites for total species richness or species diversity (Table 3-12 and 3-13; Figure 3-11 and 3-12).

A total of 36 different species of fish and invertebrates were collected in the gill nets on shoals and reference sites (Table D-1). Overall total species richness was slightly higher at the reference sites with a total of 22 fish and 5 invertebrates as opposed to 21 fish and 5 invertebrates collected on the shoals. Nine fish and one invertebrate species collected at the reference sites were not collected at the shoals, and eight fish and one invertebrate were found only on the shoals (Table D-1).

Spiny and smooth dogfish were the most abundant organisms over the two-year study, comprising 40% and 21% of the total collection, respectively. These two species exhibited a seasonal transition where spiny dogfish dominated the fall and winter collections followed by smooth dogfish making up the bulk of the catch in the spring and summer collections (Table D-1; Figure D-1 and D-2). Throughout the study, only three species were present in every season, those were bluefish, winter skate, and smooth dogfish. Due to the nature of the sampling gear, invertebrate species were collected in low numbers throughout the survey (mostly tangled in the nets or attracted by the fish caught in the nets). Among the invertebrate species collected, starfish and portly spider crab were the most frequently caught and exhibited the highest abundance (Table D-1 and D-2).

Fall

In the fall, catch per unit of effort was mixed between shoal and the reference sites (Table 3-12; Figure 3-10). Shoal D Reference (30.28±16.7 SE) and Shoal B (25.04±13.11 SE) exhibited the highest total abundance, and Shoal D (4.97±1.99 SE) and Shoal B Reference (6.75±1.85 SE) had the lowest. Significant differences were detected between Fenwick Shoal and it’s reference with an average number of 8 individuals on the shoal and 16 at the reference (Table 3-12).

Total species richness was similar between shoals and reference (Table 3-12; Figure 3-10). Weaver Shoal had the highest mean number of species and Shoal B Reference had the lowest. Species diversity was also similar between shoals and reference sites (Table 3-12; Figure 3-10). The highest diversity was found on Weaver Shoal and the lowest was found on Fenwick Shoal reference site.

A total of 9 fish and 2 invertebrate species were collected throughout the sites in the fall (Table D-1). Altogether fish were more abundant than invertebrates accounting for 96% of the total catch in the fall collections (Table D-1; Figure D-1). More fish species were collected at the reference sites than at the shoals, with 9 species at the reference sites compared to 5 at the shoals. There were two invertebrate species collected in the fall in low abundance. The Atlantic rock crab was collected at Fenwick Island Reference and starfish were collected at Fenwick Island Shoal and Shoal B. Of the 11 species collected in the fall, four fish and Atlantic rock crab occurred only at reference sites and only starfish were found only at the shoals (Table D-1).

Spiny dogfish was the most abundant species in the fall and dominated the collection accounting for 87% of the total catch (Table D-8; Figure D-1). Bluefish and striped bass were also present in limited numbers both accounting for just over 7% of the total abundance in the fall (Table D-8). Spiny dogfish was the only species present at every site and accounted for 90% of all fish collected at both the shoal and reference sites (Table D-7 and D-8). Striped bass were more prevalent on shoals than at the reference sites, and bluefish exhibited similar composition throughout all the sites (Table D-7 and D-8). Other fish species collected in the fall were winter skate, smooth dogfish, weakfish, and blueback herring.

Winter

Gillnet net catches in the winter sampling were lower than that of any other season (Table 3-12; Figure 3-10). Very few individuals in low abundances were collected throughout the sites. Just as the fall collection, the total abundance was mixed between shoal and the reference sites in the winter (Table 3-12; Figure 3-10). For the majority of the sites the average abundance was less than one in the winter due to many collections where no organisms were taken. No differences were detected for total abundance (Table 3-12).

Total species richness was similar between sites (Table 3-12). Weaver Shoal Reference exhibited the highest number of species and Fenwick Island Shoal and its reference site both had the lowest species richness values. As a consequence of low abundance and low species richness, species diversities were also lower in the winter compared to all other seasons (Table 3-12).

A total of 7 fish and 2 invertebrate species were collected throughout the sites in the winter (Table D-1). Greater numbers of fish species were collected at the reference sites than at the shoals, with 7 species at the reference sites compared to only 2 at the shoals. Two different species of invertebrate were collected in low numbers during the winter, portly spider crab and Atlantic rock crab. Of the 9 species collected in the winter, five fish and the portly spider crab occurred only at the reference (Table D-1).

Spiny dogfish was the most abundant species in the winter and dominated the collection accounting for 74% of the entire collection (Table D-8; Figure D-1). Spiny dogfish was again the only species present at every site and accounted for 95% of all fish collected at the shoals and 64% of the fish caught at the reference sites. Smooth dogfish were also collected in limited abundance at the reference sites accounting for 8% of fish in the total catch and for 16% of the fish catch at the reference sites (Table D-8; Figure D-1). Other fish species collected in the winter were alewife, striped searobin, and windowpane flounder.

Spring

In the spring, catch per unit of effort was higher on the shoals than at the reference sites (Table 3-12; Figure 3-10). Weaver Shoal (7.97±1.46 SE) and Fenwick Island Shoal (6.66±0.91 SE) exhibited the highest total abundance in the spring. Shoal B Reference (1.17± SE) had the lowest abundance and was significantly lower than its paired reference, which exhibited a mean abundance of 4 individuals (Table 3-12).

Total species richness was also greater at the shoals than at the reference sites in the spring (Table 3-12; Figure 3-10). Weaver and Fenwick Island Shoal had the highest mean total species and Shoal B Reference had the lowest. Species diversity was higher at all shoal sites except Weaver Shoal which had slightly lower diversity that its reference site. Fenwick Island Shoal exhibited the highest diversity and Shoal B Reference had the lowest (Table 3-12).

A total of 15 fish and 2 invertebrate species were collected throughout the sites in the spring. Altogether fish were more abundant than invertebrates accounting for 96% of the total catch in the spring collections. More fish species were collected at the shoals sites than at reference sites, with 12 species of fish collected at the shoals compared to only 7 species at the reference sites. Total numbers of invertebrate species at the shoals and reference sites were similar with the moon snail and portly spider crab collected at the reference sites and only the portly spider crab collected at the shoals. Of the 17 species collected in the spring, 8 fish occurred only at shoal sites and three fish and one invertebrate were found only at the reference sites.

Smooth dogfish was the most abundant species in the spring and dominated the collection accounting for 59% of the total catch (Table D-7 and D-8; Figure D-2). Atlantic menhaden and striped sea robin were also abundant in the spring, accounting for 27% of total abundance combined (Table D-1; Figure D-2). Smooth dogfish was the only species present at every site and accounted for 57% of all fish abundance on shoals and 61% of the abundance at reference sites (Table D-7). Both Atlantic menhaden and striped sea robin exhibited similar abundance on shoals and reference sites (Table D-8; Figure D-2). Several other fish species were collected in the spring; among them were winter skate, American shad, and three sharks species, the dusky, sandbar, and thresher shark.

Summer

In the summer, catch per unit of effort was generally higher at the reference sites than at the shoals sites (Table 3-12; Figure 3-10). Weaver Shoal (5.1±2.01 SE) was the only shoal with higher total abundance compared to its reference site (2.18±1.1 SE). Shoal B (0.99± 0.43 SE) had the lowest average total abundance and Fenwick Island Shoal reference had the highest (22.46±12.44 SE).

Total species richness followed the same pattern of abundance with higher species numbers at every reference site except Weaver Shoal Reference where it was slightly lower than that of Weaver Shoal (Table 3-12; Figure 3-10). Fenwick Island Shoal reference had the highest mean total species and Shoal B and D had the lowest. Species diversity was mixed between shoals and references, with Weaver Shoal and Fenwick Island Reference exhibiting the highest diversity, and Shoal D and its reference exhibiting the lowest (Table 3-12; Figure 3-10).

A total of 17 fish and 3 invertebrate species were collected throughout the sites in the summer (Table D-1). Altogether fish were more abundant than invertebrates accounting for 92% of the total catch in the summer collections. More fish species were collected at the reference sites than at shoals, with 14 species of fish collected at the reference sites compared to 10 species at the shoals. Total numbers of invertebrate species at the shoals and reference sites were similar with four at the shoals and three at reference sites. Of the 21 species collected in the spring, 7 fish occurred only at reference sites and three fish and one invertebrate were found only at the shoals (Table D-1).

Similar to the commercial trawl collections, summer gill net collections generally had more species in greater abundance, therefore more species contributed to total abundance. Smooth dogfish was collected at all the sites and was the most abundant species in the summer accounting for 21% of the entire collection (Table D-7; Figure D-2). Two species of sharks, the Atlantic sharpnose and dusky shark were abundant in the summer and accounted for 18% of total abundance. Atlantic menhaden was not collected on the shoals, but accounted for 15% of the total abundance and 31% of total fish abundance at the reference sites. Other fish species collected in the summer were Atlantic croaker, butterfish, northern searobin, and striped searobin.

Invertebrates were the most abundant in the summer than any other season in gill nets. Starfish accounted for 6% of the total abundance and 69% of the total invertebrate abundance. Portly spider crabs were collected at more sites than starfish and accounted for 17% of the total invertebrate abundance in the summer (Table D-7 and D-8). The Atlantic rock crab, lady crab, moon snails and coarsehand lady crab were the other invertebrates collected in summer.

Table 3-10. Combined two-year seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in gillnets at four shoal and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004. Significant differences between shoal and reference sites from ANOVA tests are highlighted.

Season	**Site**	**Mean Total CPUE**	**Mean Number of Spp**	**Mean Shannon**
Fall	Ref	15.57 +/- 4.56	1.94 +/- 0.17	0.48 +/- 0.1
	Shoal	13.18 +/- 3.68	2.13 +/- 0.27	0.57 +/- 0.12
Winter	Ref	0.38 +/- 0.12	0.94 +/- 0.27	0.2 +/- 0.11
	Shoal	0.46 +/- 0.18	0.69 +/- 0.18	0.11 +/- 0.07
Spring	Ref	2.49 +/- 0.55	2.13 +/- 0.38	0.71 +/- 0.19
	Shoal	5.22 +/- 0.77	2.88 +/- 0.3	0.97 +/- 0.13
Summer	Ref	8.41 +/- 3.69	3.5 +/- 0.87	1.01 +/- 0.23
	Shoal	2.57 +/- 0.67	2.5 +/- 0.32	1.04 +/- 0.18

* Highlighted denotes significant difference (alpha = 0.05)

Table 3-11. Seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in gillnets at four shoal and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004. Significant differences between shoal and reference sites from ANOVA tests are highlighted.

Season	**Site**	**Mean Total CPUE**	**Mean Number of Species**	**Mean Shannon**
Fall 02	Ref	5.97 +/- 1.94	1.75 +/- 0.16	0.46 +/- 0.14
	Shoal	6.08 +/- 1.9	1.75 +/- 0.37	0.56 +/- 0.19
Winter 03	Ref	0.24 +/- 0.16	1 +/- 0.46	0.16 +/- 0.16
	Shoal	0.02 +/- 0.02	0.25 +/- 0.16	0 +/- 0
Spring 03	Ref	2.94 +/- 0.76	2.38 +/- 0.5	0.83 +/- 0.23
	Shoal	6.11 +/- 0.95	3.13 +/- 0.23	1.05 +/- 0.12
Summer 03	Ref	16.31 +/- 6.38	5.88 +/- 1.23	1.69 +/- 0.27
	Shoal	4.15 +/- 1.05	2.88 +/- 0.3	1.22 +/- 0.14
Fall 03	Ref	25.17 +/- 7.68	2.13 +/- 0.3	0.5 +/- 0.15
	Shoal	20.28 +/- 6.33	2.5 +/- 0.38	0.58 +/- 0.16
Winter 04	Ref	0.52 +/- 0.17	0.88 +/- 0.3	0.24 +/- 0.16
	Shoal	0.89 +/- 0.28	1.13 +/- 0.23	0.22 +/- 0.14
Spring 04	Ref	2.04 +/- 0.81	1.88 +/- 0.58	0.59 +/- 0.31
	Shoal	4.33 +/- 1.2	2.63 +/- 0.56	0.89 +/- 0.24
Summer 04	Ref	0.52 +/- 0.16	1.13 +/- 0.3	0.33 +/- 0.16
	Shoal	0.99 +/- 0.35	2.13 +/- 0.55	0.86 +/- 0.33

Table 3-12. Combined two-year seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in gillnets at eight sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004. Significant differences between paired sites from ANOVA tests are highlighted.

Season	Site	Mean Total CPUE	Mean Number of Spp	Mean Shannon
Fall	Fenwick Island Shoal	7.93 +/- 2.35	2 +/- 0.41	0.51 +/- 0.22
	Fenwick Reference	16.38 +/- 1.75	2 +/- 0.41	0.34 +/- 0.19
	Shoal B	25.04 +/- 13.11	2.25 +/- 0.85	0.51 +/- 0.3
	Shoal B Reference	6.75 +/- 1.85	1.5 +/- 0.29	0.36 +/- 0.22
	Shoal D	4.97 +/- 1.99	1.75 +/- 0.25	0.5 +/- 0.2
	Shoal D Reference	30.28 +/- 16.7	2.25 +/- 0.25	0.6 +/- 0.23
	Weaver Shoal	14.8 +/- 3.17	2.5 +/- 0.65	0.77 +/- 0.31
	Weaver Reference	8.88 +/- 4.1	2 +/- 0.41	0.62 +/- 0.22
Winter	Fenwick Island Shoal	0.25 +/- 0.16	0.5 +/- 0.29	0 +/- 0
	Fenwick Reference	0.3 +/- 0.19	0.5 +/- 0.29	0 +/- 0
	Shoal B	1.01 +/- 0.6	0.75 +/- 0.48	0.2 +/- 0.2
	Shoal B Reference	0.39 +/- 0.27	1 +/- 0.41	0.23 +/- 0.23
	Shoal D	0.29 +/- 0.11	1 +/- 0	0 +/- 0
	Shoal D Reference	0.31 +/- 0.23	0.75 +/- 0.25	0 +/- 0
	Weaver Shoal	0.28 +/- 0.28	0.5 +/- 0.5	0.23 +/- 0.23
	Weaver Reference	0.53 +/- 0.32	1.5 +/- 0.96	0.57 +/- 0.34
Spring	Fenwick Island Shoal	6.66 +/- 0.91	3.5 +/- 0.65	1.13 +/- 0.22
	Fenwick Reference	3.21 +/- 0.93	2.75 +/- 0.63	1.05 +/- 0.36
	Shoal B	3.69 +/- 0.65	2.5 +/- 0.5	0.85 +/- 0.29
	Shoal B Reference	1.17 +/- 0.34	1.25 +/- 0.25	0.18 +/- 0.18
	Shoal D	2.55 +/- 1.49	2 +/- 0.41	0.73 +/- 0.27
	Shoal D Reference	1.65 +/- 0.84	1.5 +/- 0.65	0.39 +/- 0.25
	Weaver Shoal	7.97 +/- 1.46	3.5 +/- 0.65	1.19 +/- 0.3
	Weaver Reference	3.93 +/- 1.63	3 +/- 1.08	1.23 +/- 0.46
Summer	Fenwick Island Shoal	3.07 +/- 0.83	3.5 +/- 0.29	1.58 +/- 0.21
	Fenwick Reference	22.46 +/- 12.44	6 +/- 2.35	1.73 +/- 0.47
	Shoal B	0.99 +/- 0.43	1.5 +/- 0.29	0.36 +/- 0.21
	Shoal B Reference	7.47 +/- 4.67	3.75 +/- 2.06	0.98 +/- 0.57
	Shoal D	1.12 +/- 0.61	1.5 +/- 0.65	0.61 +/- 0.37
	Shoal D Reference	1.55 +/- 0.66	1.75 +/- 0.25	0.53 +/- 0.18
	Weaver Shoal	5.1 +/- 2.01	3.5 +/- 0.29	1.6 +/- 0.07
	Weaver Reference	2.18 +/- 1.1	2.5 +/- 1.32	0.81 +/- 0.5

Table 3-13. Seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in gillnets at eight sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004. Significant differences between paired sites from ANOVA tests are highlighted.

Season	Site	Mean Total CPUE	Mean Number of Species	Mean Shannon
Fall 02	Fenwick Island Shoal	8.64 +/- 5.59	2.5 +/- 0.5	0.83 +/- 0.18
	Fenwick Reference	14.02 +/- 1.68	2 +/- 0	0.24 +/- 0.02
	Shoal B	3.33 +/- 3.33	1.5 +/- 1.5	0.68 +/- 0.68
	Shoal B Reference	6.33 +/- 0.33	1.5 +/- 0.5	0.25 +/- 0.25
	Shoal D	1.56 +/- 0.34	1.5 +/- 0.5	0.46 +/- 0.46
	Shoal D Reference	1.43 +/- 0	2 +/- 0	1 +/- 0
	Weaver Shoal	10.8 +/- 1.2	1.5 +/- 0.5	0.27 +/- 0.27
	Weaver Reference	2.1 +/- 1.5	1.5 +/- 0.5	0.33 +/- 0.33
Winter 03	Fenwick Island Shoal	0 +/- 0	0 +/- 0	0 +/- 0
	Fenwick Reference	0 +/- 0	0 +/- 0	0 +/- 0
	Shoal B	0 +/- 0	0 +/- 0	0 +/- 0
	Shoal B Reference	0.18 +/- 0	1 +/- 0	0 +/- 0
	Shoal D	0.1 +/- 0.03	1 +/- 0	0 +/- 0
	Shoal D Reference	0.12 +/- 0.06	1 +/- 0	0 +/- 0
	Weaver Shoal	0 +/- 0	0 +/- 0	0 +/- 0
	Weaver Reference	0.66 +/- 0.66	2 +/- 2	0.65 +/- 0.65
Spring 03	Fenwick Island Shoal	7.09 +/- 0.55	3.5 +/- 0.5	1.01 +/- 0.21
	Fenwick Reference	3.23 +/- 0.57	3.5 +/- 0.5	1.36 +/- 0.21
	Shoal B	4.74 +/- 0.63	3 +/- 0	1.06 +/- 0.08
	Shoal B Reference	1.74 +/- 0.19	1.5 +/- 0.5	0.36 +/- 0.36
	Shoal D	4.6 +/- 2.2	2.5 +/- 0.5	0.96 +/- 0.31
	Shoal D Reference	3.09 +/- 0.18	2.5 +/- 0.5	0.78 +/- 0.28
	Weaver Shoal	8 +/- 3.33	3.5 +/- 0.5	1.19 +/- 0.45
	Weaver Reference	3.69 +/- 3.69	2 +/- 2	0.84 +/- 0.84
Summer 03	Fenwick Island Shoal	4.16 +/- 1.09	3 +/- 0	1.21 +/- 0.07
	Fenwick Reference	43.83 +/- 3.95	10 +/- 1	2.53 +/- 0.18
	Shoal B	1.74 +/- 0	2 +/- 0	0.72 +/- 0
	Shoal B Reference	14.77 +/- 4.92	7 +/- 2	1.95 +/- 0.12
	Shoal D	2.13 +/- 0.43	2.5 +/- 0.5	1.23 +/- 0.23
	Shoal D Reference	2.63 +/- 0.44	2 +/- 0	0.66 +/- 0.07
	Weaver Shoal	8.57 +/- 0	4 +/- 0	1.72 +/- 0.03
	Weaver Reference	4 +/- 0.73	4.5 +/- 1.5	1.63 +/- 0.41
Fall 03	Fenwick Island Shoal	7.21 +/- 0.87	1.5 +/- 0.5	0.19 +/- 0.19
	Fenwick Reference	18.75 +/- 2.08	2 +/- 1	0.44 +/- 0.44
	Shoal B	46.74 +/- 8.84	3 +/- 1	0.34 +/- 0.05
	Shoal B Reference	7.16 +/- 4.48	1.5 +/- 0.5	0.46 +/- 0.46
	Shoal D	8.37 +/- 0.7	2 +/- 0	0.54 +/- 0.15
	Shoal D Reference	59.13 +/- 3.04	2.5 +/- 0.5	0.2 +/- 0.04
	Weaver Shoal	18.8 +/- 5.2	3.5 +/- 0.5	1.26 +/- 0.12
	Weaver Reference	15.65 +/- 2.61	2.5 +/- 0.5	0.91 +/- 0.03

Table 3-13. (Continued)

Season	Site	Mean Total CPUE	Mean Number of Species	Mean Shannon
Winter 04	Fenwick Island Shoal	0.51 +/- 0.17	1 +/- 0	0 +/- 0
	Fenwick Reference	0.6 +/- 0.2	1 +/- 0	0 +/- 0
	Shoal B	2.01 +/- 0.4	1.5 +/- 0.5	0.41 +/- 0.41
	Shoal B Reference	0.6 +/- 0.6	1 +/- 1	0.46 +/- 0.46
	Shoal D	0.47 +/- 0	1 +/- 0	0 +/- 0
	Shoal D Reference	0.5 +/- 0.5	0.5 +/- 0.5	0 +/- 0
	Weaver Shoal	0.56 +/- 0.56	1 +/- 1	0.46 +/- 0.46
	Weaver Reference	0.39 +/- 0.39	1 +/- 1	0.5 +/- 0.5
Spring 04	Fenwick Island Shoal	6.23 +/- 2.08	3.5 +/- 1.5	1.24 +/- 0.48
	Fenwick Reference	3.2 +/- 2.21	2 +/- 1	0.75 +/- 0.75
	Shoal B	2.65 +/- 0	2 +/- 1	0.65 +/- 0.65
	Shoal B Reference	0.59 +/- 0	1 +/- 0	0 +/- 0
	Shoal D	0.5 +/- 0.17	1.5 +/- 0.5	0.5 +/- 0.5
	Shoal D Reference	0.2 +/- 0.2	0.5 +/- 0.5	0 +/- 0
	Weaver Shoal	7.94 +/- 1.32	3.5 +/- 1.5	1.18 +/- 0.59
	Weaver Reference	4.17 +/- 1.5	4 +/- 1	1.62 +/- 0.53
Summer 04	Fenwick Island Shoal	1.97 +/- 0.76	4 +/- 0	1.95 +/- 0.05
	Fenwick Reference	1.09 +/- 0.1	2 +/- 0	0.92 +/- 0
	Shoal B	0.24 +/- 0	1 +/- 0	0 +/- 0
	Shoal B Reference	0.17 +/- 0.17	0.5 +/- 0.5	0 +/- 0
	Shoal D	0.12 +/- 0.12	0.5 +/- 0.5	0 +/- 0
	Shoal D Reference	0.47 +/- 0.28	1.5 +/- 0.5	0.41 +/- 0.41
	Weaver Shoal	1.62 +/- 0.32	3 +/- 0	1.48 +/- 0.02
	Weaver Reference	0.35 +/- 0.35	0.5 +/- 0.5	0 +/- 0

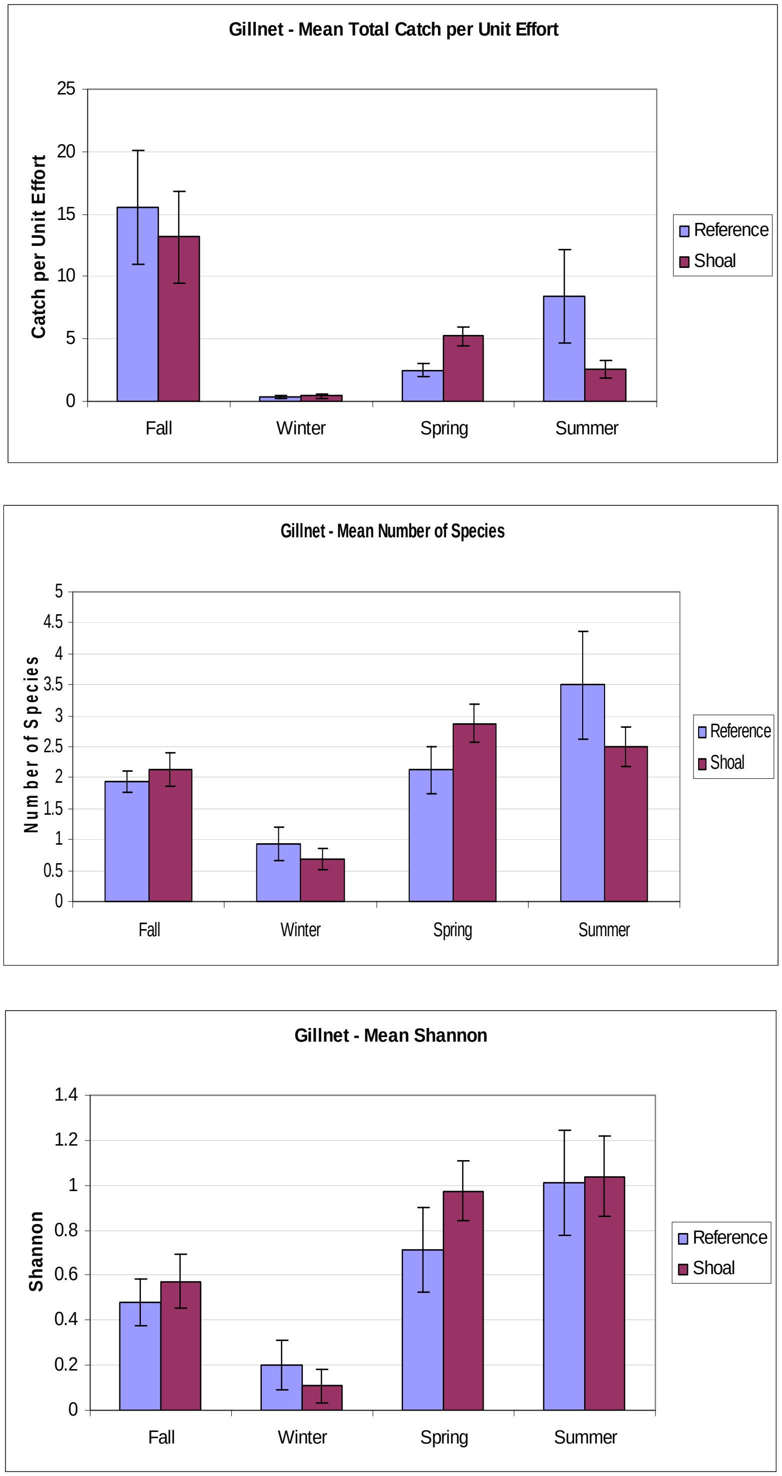


Figure 3-9. Combined two-year seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in gillnets at four shoal and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.

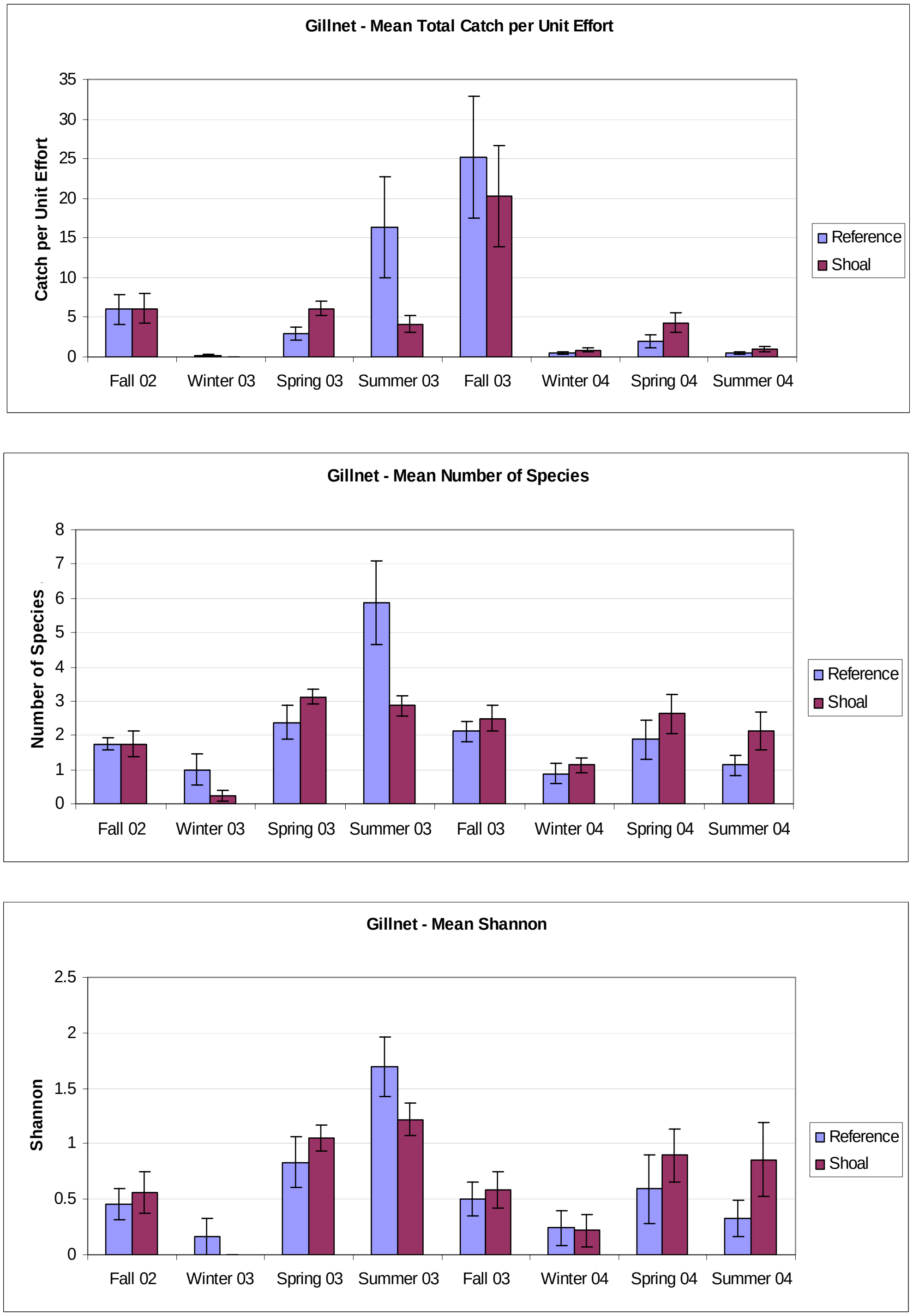


Figure 3-10. Seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in gillnets at four shoal and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.

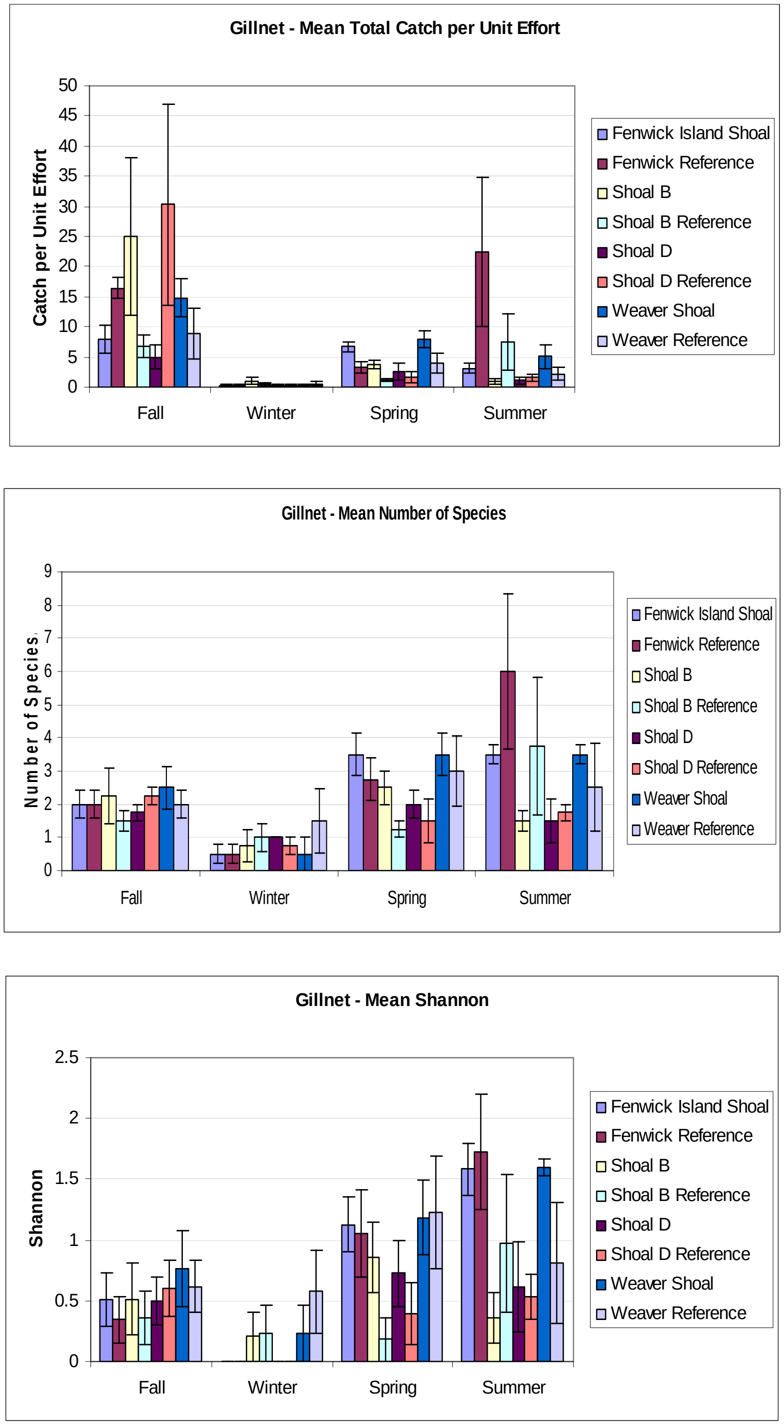


Figure 3-11. Combined two-year seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in gillnets at eight sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.

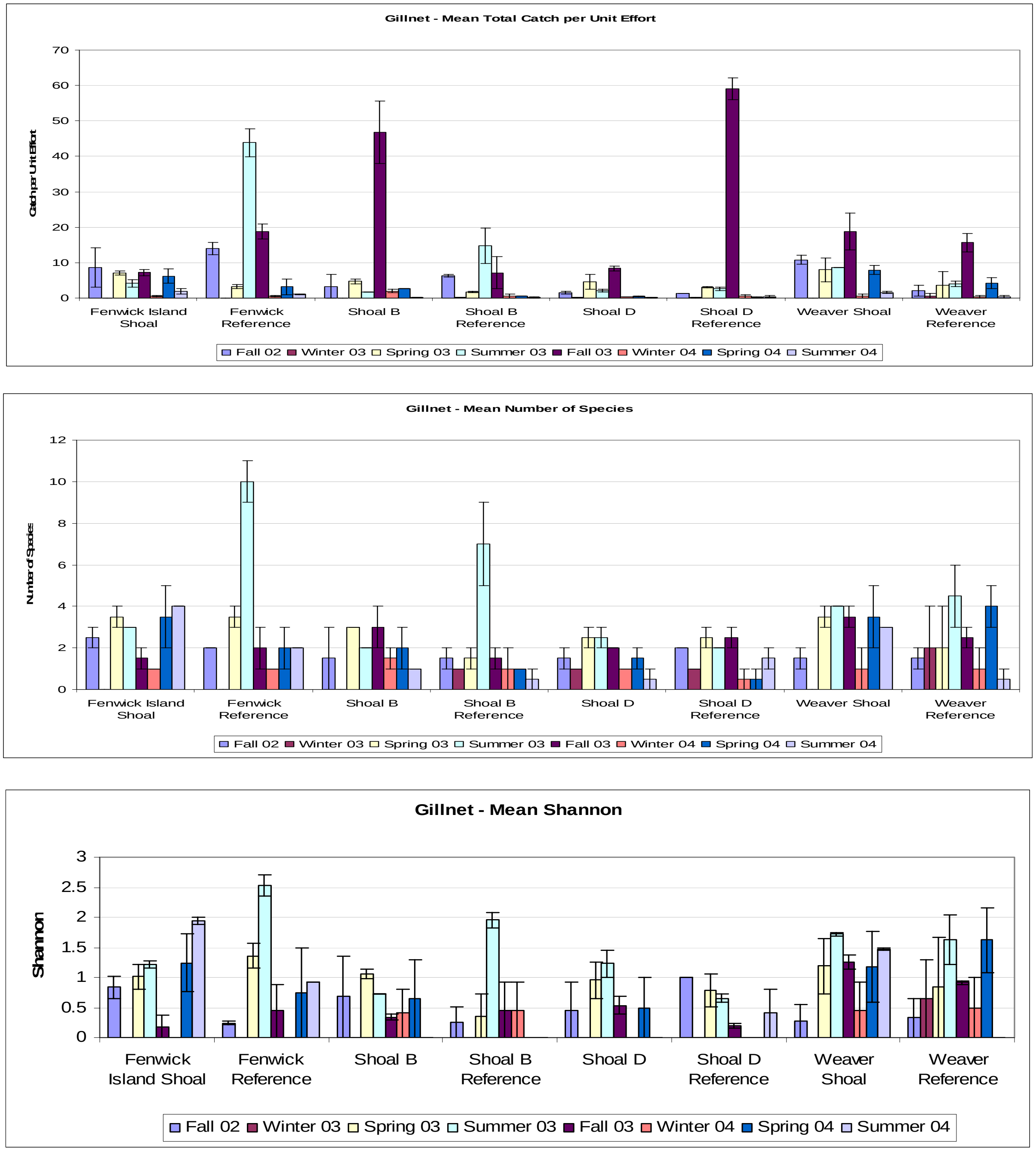


Figure 3-12. Seasonal mean (and SE) of total species CPUE, number of species, and species diversity collected in gillnets at eight sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.

3.2 SPECIES GUILD AND META ANALYSIS

3.2.1 Species Guild and Meta-Analysis Methods

Data were standardized to catch per unit of effort (CPUE) before analysis, where units were the number of animals captured per 10,000 m^2 of area swept by the trawls, and number captured per hour of soak time in gillnets. These estimates were transformed to $\log_e$ (CPUE + 1) before analysis to meet the assumption of equal variance among treatments for ANOVA. We conducted ANOVA with $\log_e$ (CPUE +1) as the response variable, site and season as blocks, and treatment (shoal or reference) as a factor, using the SAS GLM procedure (SAS Institute 2004).

The analysis was performed for each combination of gear and guild except pelagic invertebrates in gillnets, because no invertebrates were captured in them. Guilds were defined using life history information. For this study we defined a guild based on feeding strategies found in the literature, such as primarily benthic oriented feeding or pelagic feeding strategies. Four functional groups or guilds were defined from the fisheries data: benthic finfish, benthic invertebrates, pelagic finfish, and pelagic invertebrate (Table 3-1). Essentially squid was the pelagic invertebrate guild, because no other pelagic invertebrates were collected.

Individual cell means were plotted for each gear and visually inspected for interactions between the effects of treatment, site, and season. Because interactions did not follow any consistent pattern among gears and did not appear to be biologically plausible, they were not included in the analyses of variance. For each ANOVA, the least-squares mean difference in transformed CPUE between shoals and reference sites was calculated for use in a meta-analysis.

Meta-analysis was conducted for each guild to judge the overall pattern in abundance across sampling gears. In this analysis, sampling with each gear was viewed as an independent field experiment that measured the effect of shoals on abundance of fish and invertebrates. Estimates of effect sizes (differences in abundance between shoals and reference sites) differed among gears not only because they included sampling variation, but also because each gear captured fish and invertebrates with different efficiency. However, the differences in efficiency likely affected only the mean and standard deviation of the estimate for each experiment, not the size of the effect on abundance of fish and invertebrates. That is, effects estimated for each experiment were hypothesized to be linearly equitable because all three gears were deployed to sample the same true differences in fish and invertebrate abundance. The result of the meta-analysis was an estimate of the difference in abundance between shoal and reference areas for each guild scaled to the standard normal curve (i.e., mean 0 and SD 1), and pooled across multiple sampling gears.

The meta-analysis was conducted following Hedges and Olkin (1985). First, standardized mean differences in transformed CPUE between shoal and reference sites (d_i) were calculated for each ANOVA using the unbiased estimator:

$$d_i = \left(1 - \frac{3}{4N-9}\right) J(N-2) \frac{\overline{Y}^{\mathrm{E}} - \overline{Y}^{\mathrm{C}}}{s}$$

Where:

N = the total number of samples,
$\overline{Y}^{\mathrm{E}}$ = the mean abundance for shoals,
$\overline{Y}^{\mathrm{C}}$ = the mean abundance for reference areas,
s = the standard deviation of the treatment effect,
and the function $J(m) = 1 - \frac{3}{4m-1}$.

Standardized estimates within each guild were then tested for homogeneity using the Q statistic:

$$Q = \sum_{i=1}^{k} \frac{(d_i - d_+)^2}{\hat{\delta}^2(d_i)}$$

Where:

k = the number of experiments,
$$d_+ = \sum_{i=1}^{k} \frac{d_i}{\hat{\delta}^2(d_i)} \Bigg/ \sum_{i=1}^{k} \frac{1}{\hat{\delta}^2(d_i)},$$
$$\hat{\delta}^2 = \frac{N}{n^E n^C} + \frac{d_i^2}{2N},$$
n^E = number of shoal samples,
and n^C = number of reference samples.

The Q statistic has an asymptotic chi-square distribution with $k - 1$ degrees of freedom. A significant chi-square result indicates that the pooled experiments can not be described as sharing a common effect size. Gillnet data were excluded from the meta-analysis because the test of homogeneity indicated that the three experiments probably did not measure the same effect sizes for two of the four guilds (Benthic finfish, $Q = 7.01$, $P = 0.97$, and Pelagic Finfish, $Q = 7.25$, $P = 0.97$). When the data were combined for both trawl experiments, the homogeneity test was not significant at the 10% level for any group, indicating that the trawl data could reasonably be pooled to estimate the relative magnitude of effects.

Estimates of effect sizes pooled over the two trawl gears were calculated for each guild as d_+ above, with variance:

$$\delta^2(d_+) = \left(\sum_{i=1}^{k} \frac{1}{\delta^2(d_i)} \right)^{-1}$$

Where:

$\delta^2(d_i)$ = the variance of d_i

3.2.1.1 Species Guild and Meta-Analysis Results

Results from these analysis show that more benthic finfish, pelagic finfish, and pelagic invertebrates (squid) were captured in the commercial and small trawls at reference sites than at shoals (Figure 3-13; Table 3-14). The difference was statistically significant at $\alpha = 0.05$ for all of these comparisons except benthic finfish in the commercial trawl, which had $\alpha = 0.058$. However, each of the trawl gears captured benthic invertebrates in nearly equal numbers at shoal and reference sites. Capture rates in gillnets differed from those in trawls. In gillnets, all guilds except pelagic invertebrates were captured in about equal numbers, and no significant differences were detected. No pelagic invertebrates were captured in gillnets.

Meta-analysis of the trawl gears confirmed that benthic finfish, pelagic finfish, and pelagic invertebrates occurred in greater densities at reference sites than at shoals (Table 3-15). The standardized difference in mean transformed densities was about 0.5 standard deviations for all three guilds, and 95% confidence intervals indicated the difference was probably at least 0.2 standard deviations for all three guilds. There was little evidence that benthic invertebrate density differed between shoal and reference sites, as indicated by the small standardized difference between mean densities (0.01 standard errors) and associated 95% confidence interval that intersected zero by a large amount.

Table 3-14. Results of analyses of variance for treatment effects (shoal versus reference sites) on the model, $\log_e$ (CPUE + 1) = treatment + site + season, by gear and species guild. Effect sizes are shown in Figure 3-13. The habitat with the higher treatment values for a specific test is indicated by an S (shoal) or R (reference). An asterisk indicates a test was significant at the $\alpha = 0.05$ level.

Gear	**Guild**	***F***	***P***
Commercial trawl	Benthic finfish	3.66	0.058 (R)
	Pelagic finfish	8.29	0.005^* (R)
	Benthic Invertebrates	0.38	0.538 (S)
	Pelagic Invertebrates	6.25	0.014^* (R)
Small trawl	Benthic finfish	11.07	0.001^* (R)
	Pelagic finfish	12.62	$<0.001^*$ (R)
	Benthic Invertebrates	0.27	0.605 (R)
	Pelagic Invertebrates	5.53	0.021^* (R)
Gillnet	Benthic finfish	0.02	0.893 (S)
	Pelagic finfish	<0.01	0.950 (R)
	Benthic Invertebrates	0.55	0.458 (S)
	Pelagic Invertebrates	NA	NA

Table 3-15. Standardized mean differences in $\log_e$ (CPUE + 1) captured at shoals versus reference sites from meta-analysis of commercial and small trawl surveys, for each species guild. Negative numbers indicate more animals were captured in reference areas.

Group	**Standardized effect**	**95% Confidence limits**	
		Lower	**Upper**
Benthic finfish	-0.47	-0.22	-0.73
Benthic invertebrates	0.01	0.27	-0.24
Pelagic finfish	-0.58	-0.32	-0.84
Pelagic invertebrates	-0.44	-0.18	-0.70

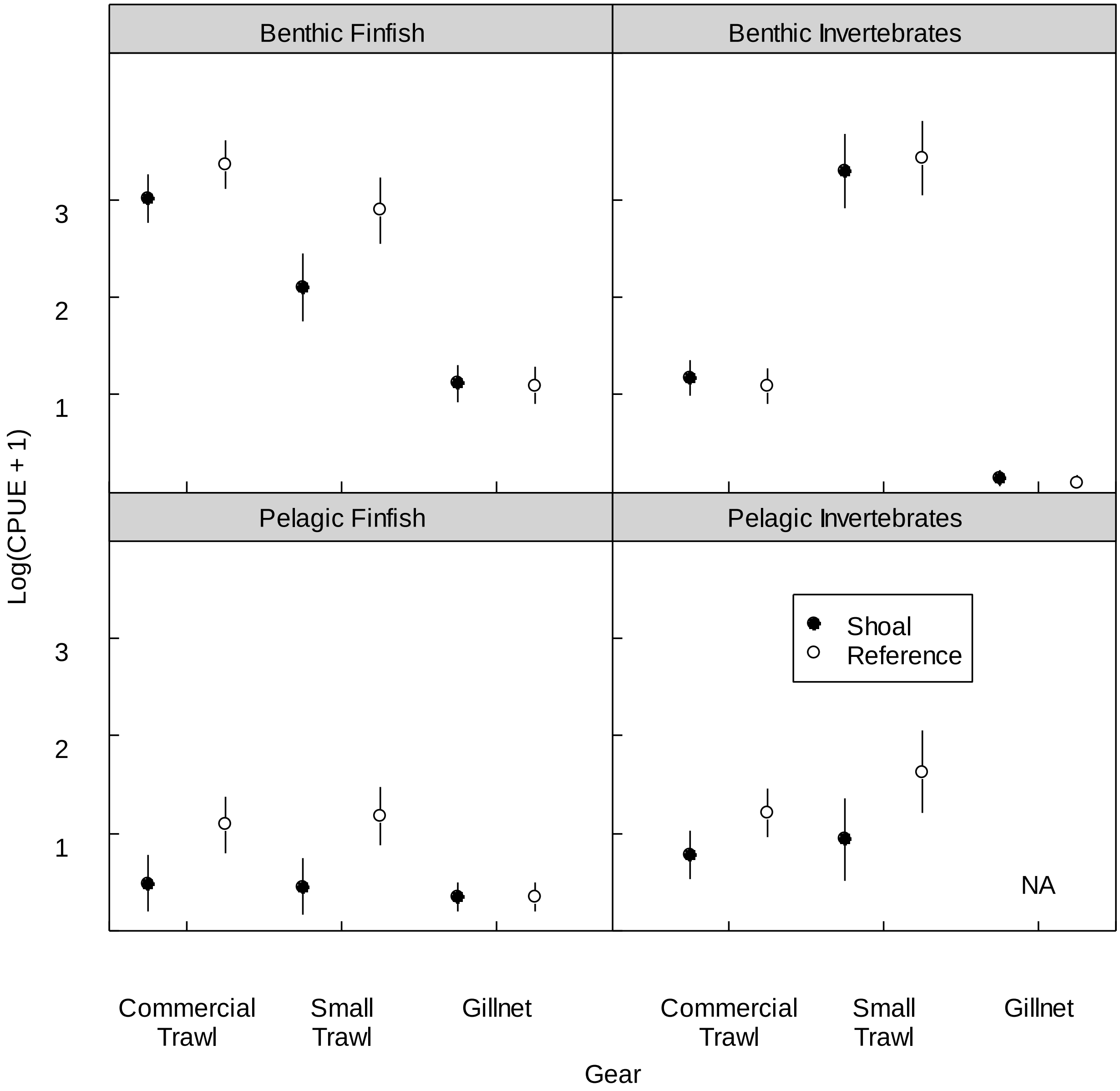


Figure 3-13. Least-squares means (± 95% CI) for $\log_e$ (CPUE + 1) at shoals and reference sites from the model $\log_e$ (CPUE + 1) = treatment + site + season, by gear and species guild.

3.3 MULTIVARIATE ANALYSIS

3.3.1 Multivariate Analysis Methods

Multivariate analyses were used to elucidate whether differences between shoal and reference sites were attributed to differences in faunal composition as quantified by the three net gears used in this study. Specifically, the objectives of these analyses were (1) to assess whether there were differences in species composition between the shoal and the reference sites, and (2) examine whether these differences were maintained in all seasons and different years.

Multivariate analyses were carried out using the routines in the PRIMER (Plymouth Routines in Multivariate Ecological Research) v.5 statistical package (Clarke and Gorley 2001). Species abundance data were log-transformed as described in the Total Catch Analysis section, and subjected to cluster analysis and non-metric multidimensional scaling (MDS) ordination on a Bray-Curtis similarity matrix (Clarke and Warwick 2001). The group average method was used to link sites in cluster analysis. Transformation was used prior to calculating similarities in order to balance the contribution of abundant species with high CPUE against those of less common species. Analyses of small trawl data excluded bay anchovies (*Anchoa mitchilli*) because this is a pelagic species that is only occasionally collected in high numbers in trawls. This species exhibits a strong tendency to form schools and thus introduces large variability in the analyses. Such species tend to obscure the pattern and interpretation of the multivariate analyses.

Non-metric MDS is one of many ordination techniques. It was chosen here for its simplicity of concept. Non-metric MDS constructs a plot in which samples are arranged in rank order according to their relative similarity. Main advantages of non-metric MDS over other ordination methods (e.g., Principal Component Analysis) are the lack of assumptions about species distributions, and a greater ability to represent accurately the complex relations among the samples. The algorithm involves non-parametric regression, and the success of the ordination is measured by the level of scatter in the regression, or “stress”.

Two-way crossed ANOSIM tests (Analysis of Similarities) were used to test for differences in species composition between the shoals and the reference sites after blocking for the effects of season. Significant differences produced by the ANOSIM test are determined by the R-statistic value. The R statistic reflects the observed differences between groups (in this case shoal versus reference sites) contrasted with differences among replicates within groups. Within each shoal and reference group, sites (i.e., Shoal B, and Shoal D, Fenwick Island Shoal, and Weaver Shoal) and years were treated as replicates. R is based on the rank similarities between samples and usually ranges from +1, when all samples within groups are more similar to each other than to any sample from other groups, to 0, when average similarities within and between groups are the same (i.e., the null hypothesis). The observed value of R is then compared to the spread of all the R values possible from the random re-labeling of samples, or to a subset of these values if the number of permutations is high (> 1,000). The null hypothesis of no difference between groups is rejected if the observed value of R looks unlikely to have come from the distribution of R values given by the random rearrangements. For the two-way crossed design, the observed R is calculated for each separate block (in this case season), and the resulting values averaged. Its permutation distribution under the null hypothesis was generated by examining the random re-labeling of sites (shoal and reference) within each season.

For ANOSIM tests that were significant, the SIMPER procedure (Similarity Percentages) was used to identify which species were responsible for the separation of samples in the MDS ordination, and to characterize shoal and reference sites. The analysis identifies which species contribute most to the average dissimilarity between groups of sites (e.g., shoal vs. reference sites) and which species contribute more consistently (by examining the ratio of the average dissimilarity contribution of each species to its standard deviation). Differences in mean CPUE of species contributing most to the separation between the shoal and the reference sites were examined graphically by overlaying on the ordination plot circles of size proportional to the magnitude of the abundance. Total CPUE and total species richness among sites was also examined in this way.

For the purposes of the multivariate analysis the samples were coded to indicate area, treatment, season, and year. For example Weaver Shoal winter 2003 was coded WS-1-03, where WS=Weaver Shoal, 1= winter, and 03 = year 2003.

The various seasons were coded:
Winter=1, spring = 2, summer = 3, and fall = 4

The sampling sites were coded:
Weaver Shoal =WS, Weaver Reference =WR, Fenwick Shoal = FS, Fenwick Reference = FR, Shoal B = BS, Shoal B Reference = BR, Shoal D = DS, Shoal D Reference =DR.

3.3.1.1 Multivariate Analysis Results

For all three gears, there was strong separation of sites according to season in cluster analysis (Figure 3-14). Individual samples linking at very low similarity values (DS-2-03, FS-3-03, WS-1-04, and BR-1-03) had low abundance and 1-3 species, generally invertebrates. A few other samples had no catch in gillnets (BS-1-03, FR-1-03, FS-1-03, and WS-1-03) or in small trawls (BR-4-02, DR-4-02, and FR-4-02). Samples with no catch were excluded from the analyses. Year was also a factor contributing to the separation of sites, but its effect was less distinct than season.

Given the strong effect of seasonality, data were examined within each season and ordination plots constructed to examine site configuration and whether there was any tendency for sites to form groups according to location (shoal vs. reference). Shoal and reference samples collected with the small trawl showed a tendency to form groups in spring and summer, but not in fall or winter (Figure 3-15). For the commercial trawl samples, there was a tendency for shoal and reference samples to group in summer, a clearer pattern of separation in fall and winter, and no pattern in spring (Figure 3-16). No structure existed for the gillnet samples that would suggest differences between the shoal and the reference sites (Figure 3-17). There was also clear segregation of samples according to year in the MDS plots (not shown) for all seasons and gears.

Two-way crossed ANOSIM tests with location (shoal vs. reference) as the main factor, and seasons as blocks, detected a significant difference between sites for the commercial trawl data, a difference at the 10.9% level for the small trawl, and no difference for the gillnet. The simulated distributions of the R statistic under the null hypothesis of no differences between shoal and reference sites can be examined in Figure 3-18. For the commercial trawl, an observed value of R of 0.18 is a very unlikely event and leads to the rejection of the null hypothesis at the 0.1% level. For the small trawl, a significant difference can be inferred given that only a relatively small number (10.9%) of the simulated R values is larger than the observed R of 0.06. For this last analysis, the 2002 fall samples were excluded because of the gear problems discussed elsewhere in this report. For gillnets, the observed R is negative and below 72% of the simulated R values. For this last gear, shoal and reference sites were undistinguishable. Season was highly significant for all tests.

The results of the two-way crossed ANOSIM tests suggest that despite the strong effects of season (and the further differences in year identified in the MDS plots), differences in species composition between the shoal and the reference sites could be interpreted for the small trawl and commercial trawls. SIMPER was then used for these two gears to determine which species typified the shoal and the reference sites.

Many species played at least some part in determining the dissimilarity between the shoal and the reference sites. Those that contributed to 90% of the dissimilarity are listed in Tables 3-16 and 3-17. However, about 40% of the dissimilarity was accounted for by three species in the small trawl and by 3-5 species in the commercial trawl. Species contributing most to the separation between the shoal and the reference sites varied across seasons. For the small trawl, sand shrimp, spotted hake, and moon snails contributed most in the winter; spotted hake, squids, and right-handed hermit crabs in spring; and squids, right-handed hermit crabs, and starfishes in summer and fall (Table 3-16). No one species was “best” discriminator (high dissimilarity to standard deviation ratio), except perhaps the northern searobin in summer commercial trawls. The influence of spotted hake in the spring and of northern searobin in the summer small trawls can be observed in Figure 3-19. Both fish species were on average more abundant in the reference than in the shoal sites.

For the commercial trawl the striped bass and several other species more equally contributed to the separation between shoal and reference sites in the fall; winter skate, windowpane, and little skate contributed most in winter; scup, butterfish, and squids in the spring; northern searobin, scup, and squid in the summer (Table 3-17). Again, many species contributed to the discrimination between the shoal and the reference sites, but none better than scup in the fall, winter skate in winter, and northern searobin in summer (Figure 3-20). All three fish species were more abundant in the reference than in the shoal sites.

Table 3-16. Average dissimilarity (Av.Diss) and percent contribution of species (Contrib%) to the separation of shoal and reference sites, by season, for the small trawl. The average abundance in shoal (S) and reference sites (R). The dissimilarity to standard deviation ratio (Diss/SD), a measure of how well a species discriminates between the groups of sites (the larger the better), is also indicated in the table.

Species	Group S	Group R	Av.Diss	Diss/SD	Contrib%	Cum.%
	Av.Abund	Av.Abund				
Fall (Average dissimilarity = 61.10)						
Squids	16.92	20.21	9.24	1.29	15.12	15.12
Starfishes	11.22	12.84	7.9	1.66	12.92	28.04
Right handed hermit crabs	4.01	13.15	6.78	1.41	11.09	39.14
Atlantic croaker	0.46	9.87	6.7	1.08	10.96	50.1
Spotted hake	3.69	3.53	3.91	1.2	6.4	56.5
Smallmouth flounder	0.76	1.64	3.24	1.36	5.31	61.81
Windowpane	0.44	1.39	3.01	1.11	4.92	66.73
Winter skate	1.03	1.04	2.93	1.32	4.79	71.52
Moon snails	0.91	0	2.6	0.88	4.25	75.77
Silver hake	0.49	0.53	1.91	0.67	3.12	78.89
Scup	0	0.99	1.88	1.04	3.08	81.97
Northern searobin	0.39	0.44	1.74	0.97	2.85	84.83
Lady crab	0.26	0.53	1.66	1.1	2.72	87.55
Clearnose skate	0.32	0.35	1.54	0.93	2.51	90.06
Winter (Average dissimilarity = 48.54)						
Sand shrimp	4.2	9.81	6.86	1.41	14.14	14.14
Spotted hake	0.87	3.69	6.75	1.37	13.91	28.05
Moon snails	2.3	3.68	6.58	1.51	13.56	41.61
Gastropods	2.7	1.47	5.47	0.69	11.27	52.88
Starfishes	0.68	3.3	5.38	1.06	11.08	63.97
Right handed hermit crabs	2.98	2.9	3.24	1.39	6.67	70.63
Atlantic silverside	0.17	0.63	2.88	0.88	5.92	76.56
Little skate	0.35	0.58	2.86	1.12	5.88	82.44
Smallmouth flounder	0.26	0.48	2.3	0.93	4.74	87.18
Windowpane	0.17	0.28	1.42	1.06	2.93	90.11
Spring (Average dissimilarity = 65.48)						
Spotted hake	0.39	5.24	10.11	1.13	15.44	15.44
Squids	9.84	5.42	8.29	1.42	12.66	28.09
Right handed hermit crabs	7.27	4.53	6.94	1.27	10.59	38.69
Starfishes	3.74	4.89	5.98	1.26	9.14	47.82
Gastropods	3.58	1.8	4.88	1.01	7.45	55.28
Sand shrimp	1.67	1.27	4.14	1.16	6.32	61.6
Northern searobin	0.5	2.63	3.91	0.81	5.97	67.57
Smallmouth flounder	0.73	1.25	3.57	1.11	5.46	73.03
Moon snails	1.17	1.1	3.52	1.4	5.38	78.41
Windowpane	0.61	0.16	1.79	0.97	2.74	81.14

Table 3-16. (Continued)

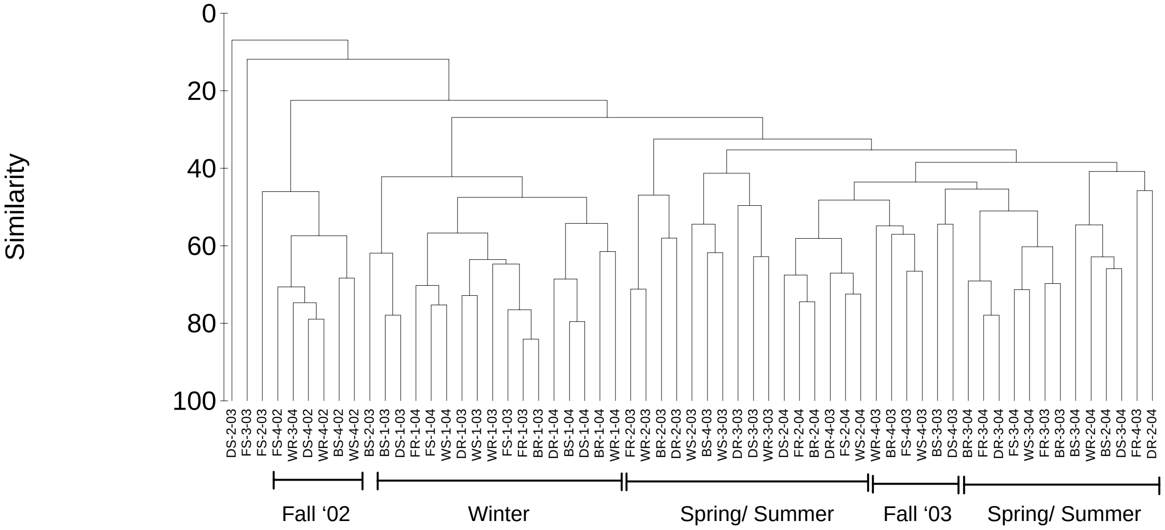
Species	Group S	Group R	Av.Diss	Diss/SD	Contrib%	Cum.%
	Av.Abund	Av.Abund				
Spring (cont'd) (Average dissimilarity = 65.48)						
Winter skate	0.56	0.16	1.75	1.05	2.68	83.82
Atlantic rock crab	0.71	0.1	1.25	0.63	1.91	85.73
Striped searobin	0.17	0.15	1.13	0.58	1.73	87.46
Black sea bass	0	0.44	1.12	0.35	1.72	89.18
Butterfish	0	0.22	0.99	0.48	1.52	90.69
Summer (Average dissimilarity = 64.08)						
Squids	4.11	39.69	9.22	1.01	14.39	14.39
Right handed hermit crabs	22.27	7.57	7.59	1.34	11.85	26.23
Starfishes	3.31	10.35	6.97	1.29	10.88	37.12
Northern searobin	0.98	11.99	5.88	1.46	9.18	46.3
Scup	3.48	1.82	5.06	1.09	7.9	54.2
Butterfish	1.28	1.9	3.6	1.09	5.62	59.82
Lady crab	1.71	1.72	3.31	1.05	5.16	64.98
Clearnose skate	1.16	1.64	3.19	1.24	4.98	69.96
Gastropods	2.66	0	2.64	0.54	4.12	74.08
Smallmouth flounder	0.46	1.29	2.21	1.27	3.45	77.53
Striped anchovy	0	0.99	1.97	0.55	3.07	80.6
Heart urchins	0.44	0.11	1.86	0.64	2.91	83.51
Spotted hake	0.05	0.38	1.18	0.77	1.85	85.35
Striped cusk eel	0	0.6	1.18	0.55	1.84	87.2
Atlantic rock crab	0	0.51	1.04	0.72	1.62	88.81
Portly spider crab	0.12	0.38	0.98	0.79	1.52	90.34

Table 3-17. Average dissimilarity (Av.Diss) and percent contribution of species (Contrib%) to the separation of shoal and reference sites, by season, for the commercial trawl. The average abundance in shoal (S) and reference sites (R). The dissimilarity to standard deviation ratio (Diss/SD), a measure of how well a species discriminates between the groups of sites (the larger the better), is also indicated in the table.

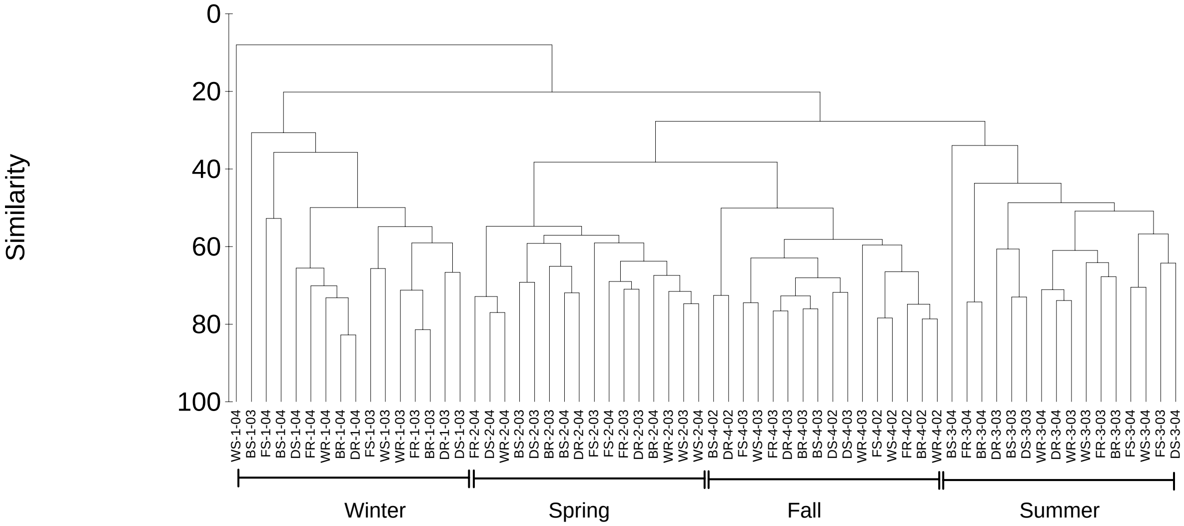
Species	**Group S**	**Group R**	**Av.Diss**	**Diss/SD**	**Contrib%**	**Cum.%**
	Av.Abund	**Av.Abund**				
Fall (Average dissimilarity = 42.05)						
Striped bass	80.57	0.6	3.23	0.88	7.67	7.67
Windowpane	4.03	31.48	3.21	1.38	7.64	15.31
Scup	0.26	5.2	3.11	2.31	7.38	22.7
Starfishes	14.56	7.67	2.92	1.16	6.94	29.63
Little skate	11.41	7.69	2.83	1.24	6.72	36.36
Spiny dogfish	55.49	94.38	2.59	1.44	6.15	42.51
Squids	2.28	7.14	2.12	1.27	5.04	47.55
Striped searobin	0.65	5.49	1.82	0.99	4.32	51.87
Clearnose skate	4.68	3.35	1.72	1.23	4.09	55.96
Bluefish	1.37	4.23	1.7	1.39	4.04	60
Summer flounder	7.89	4.59	1.62	1.17	3.84	63.85
Butterfish	0.21	2.58	1.62	1.36	3.84	67.69
Horseshoe crab	0.54	2.53	1.42	1.2	3.37	71.05
Lady crab	6.64	8.79	1.21	0.92	2.87	73.92
Weakfish	0	2.4	1.19	0.74	2.84	76.76
Bay anchovy	0	8.37	1.17	0.55	2.79	79.55
Winter skate	64.86	44.94	1.16	1.26	2.77	82.32
Smooth dogfish	0.5	0.79	0.97	1.02	2.31	84.63
Northern searobin	0.19	1.85	0.93	0.76	2.22	86.86
Coarsehand lady crab	0.48	0.72	0.84	0.81	2	88.85
Channeled whelk	0.63	0.62	0.81	1.22	1.94	90.79
Winter (Average dissimilarity = 58.78)						
Winter skate	1.54	9.48	11.82	1.69	20.1	20.1
Windowpane	1.86	5.26	7.39	1.22	12.58	32.68
Little skate	2.27	4.02	6.66	1.19	11.32	44
Atlantic herring	1.53	2.17	4.61	0.89	7.85	51.85
Spiny dogfish	0.93	1.04	4.36	0.9	7.42	59.27
Barndoor skate	0.49	1.04	3.64	0.91	6.19	65.45
Starfishes	0.65	0.49	2.81	1.17	4.79	70.24
Horseshoe crab	0.36	0.71	2.72	0.96	4.63	74.87
Atlantic menhaden	0	0.45	2.38	0.7	4.05	78.91
American sand lance	1.29	0	2.28	0.55	3.88	82.8
Blueback herring	0.15	0.41	2.04	0.97	3.47	86.26
Summer flounder	0.07	0.42	1.77	0.8	3.01	89.27
Atlantic silverside	0.07	0.14	1.13	0.64	1.93	91.2

Table 3-17. (Continued)

Species	Group S	Group R	Av.Diss	Diss/SD	Contrib%	Cum.%
	Av.Abund	Av.Abund				
Spring (Average dissimilarity = 41.23)						
Scup	483.61	103.56	5.55	1.44	13.46	13.46
Butterfish	101.66	373.11	5.42	1.12	13.15	26.62
Squids	66.06	55.92	4.53	1.4	10.97	37.59
Northern searobin	10.95	26.94	3.27	1.06	7.92	45.51
Starfishes	4.65	2.58	2.36	1.07	5.71	51.22
Striped searobin	4.29	2.14	2.29	1.32	5.55	56.77
Clearnose skate	3.66	0.15	2.18	1.04	5.28	62.05
Smooth dogfish	19.51	12.29	1.92	1.4	4.66	66.71
Little skate	10.93	5.65	1.85	1.38	4.48	71.19
Summer flounder	0.76	1.5	1.43	1.52	3.46	74.65
Winter skate	22.4	19.74	1.33	1.38	3.23	77.88
Spotted hake	0.48	1.99	1.3	1.17	3.15	81.03
Northern kingfish	0.72	0.59	1.03	1.06	2.49	83.52
Windowpane	3.15	2.44	0.92	1.26	2.23	85.75
American sand lance	0.74	0.08	0.77	0.59	1.87	87.62
Channeled whelk	0.2	0.81	0.77	0.75	1.86	89.48
Horseshoe crab	0.21	0.42	0.75	1.01	1.82	91.31
Summer (Average dissimilarity = 53.20)						
Northern searobin	25.95	90.94	5.39	1.31	10.13	10.13
Scup	171.46	18.93	4.52	0.94	8.49	18.63
Squids	12.93	24.43	4.45	1.15	8.37	27
American sand lance	42.46	0.89	3.82	0.68	7.18	34.18
Butterfish	0.4	5.43	3.53	1.13	6.63	40.81
Atlantic croaker	0	79.62	3.44	0.6	6.47	47.28
Clearnose skate	11.16	5.23	3.32	1.35	6.24	53.52
Coarsehand lady crab	9.01	2	3.07	1.18	5.78	59.3
Lady crab	28.3	10.79	2.58	1.19	4.85	64.15
Starfishes	2.09	1.86	2.35	1.11	4.41	68.56
Spotted hake	0.13	2.33	2.3	0.96	4.33	72.89
Winter skate	0.28	2.64	1.99	0.6	3.74	76.63
Windowpane	0.39	1.03	1.37	1.73	2.58	79.22
Spot	0	2.27	1.26	0.55	2.37	81.58
Bullnose ray	0.15	0.99	1.2	0.85	2.25	83.83
Summer flounder	0.21	0.8	1.14	1.14	2.14	85.98
Weakfish	0	1.07	1.01	0.56	1.89	87.87
Striped searobin	0.07	0.37	0.62	0.53	1.17	89.04
Atlantic rock crab	0	0.27	0.59	0.94	1.11	90.15



Small Trawl Data



Commercial Trawl Data

Figure 3-14. Cluster analysis of sites based on species composition and abundance for the three gears used in this study. Dendrograms show strong separation of sites by season. Labels: first letter indicates site (F = Fenwick, W = Weaver, B = Shoal B, D = Shoal D); second letter, location (R = reference, S = shoal); first digit, season (1 = Winter, 2 = Spring, 3 = Summer, 4 = Winter); last two digits, year (2002 through 2004).

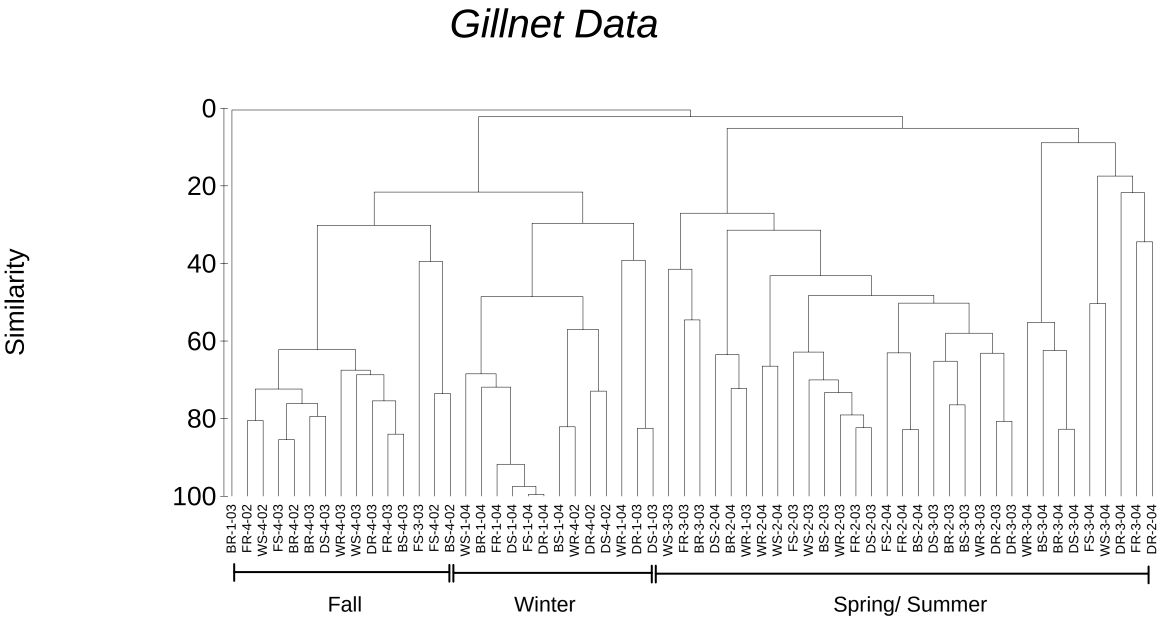


Figure 3-14. (Continued)

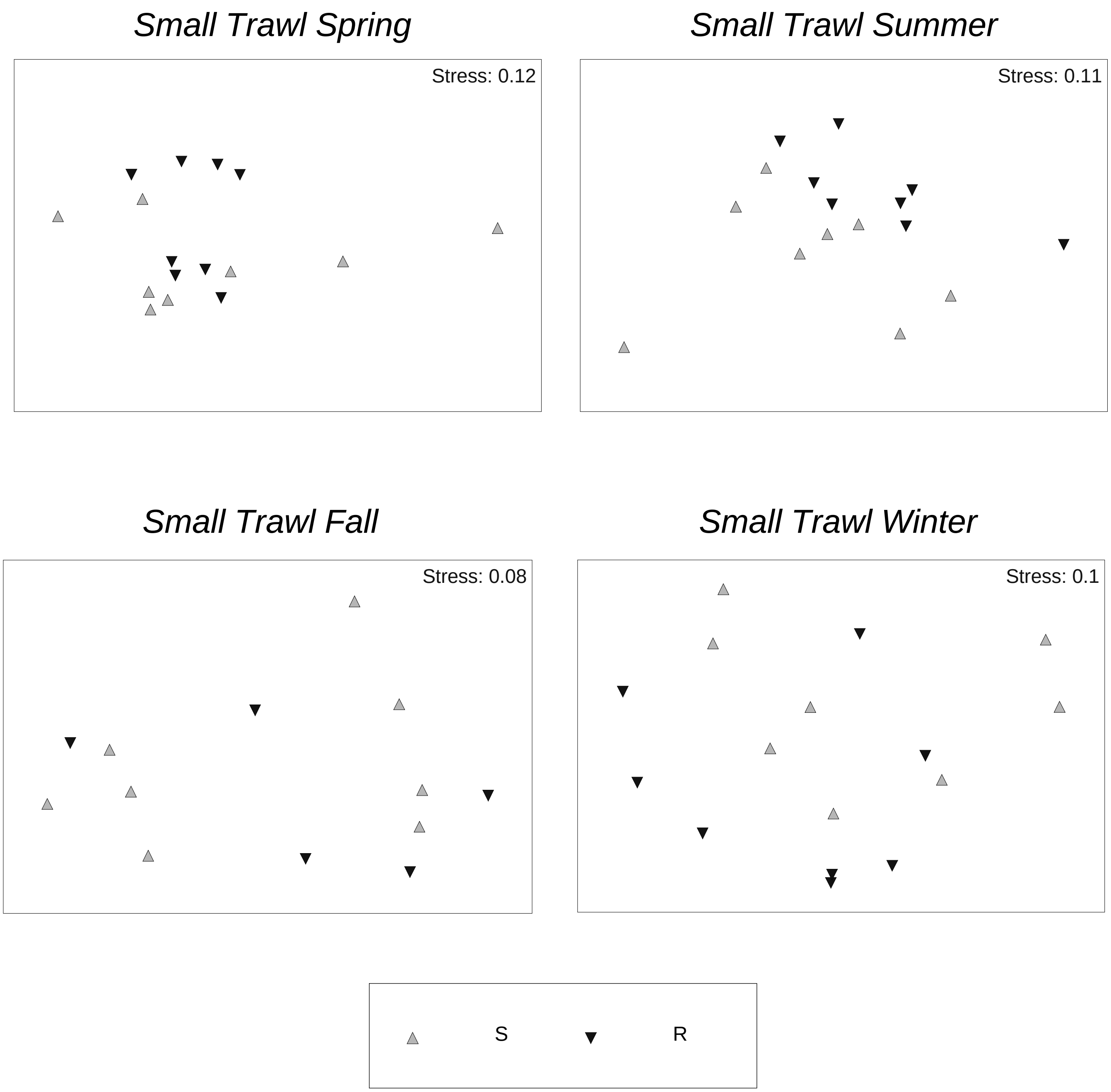
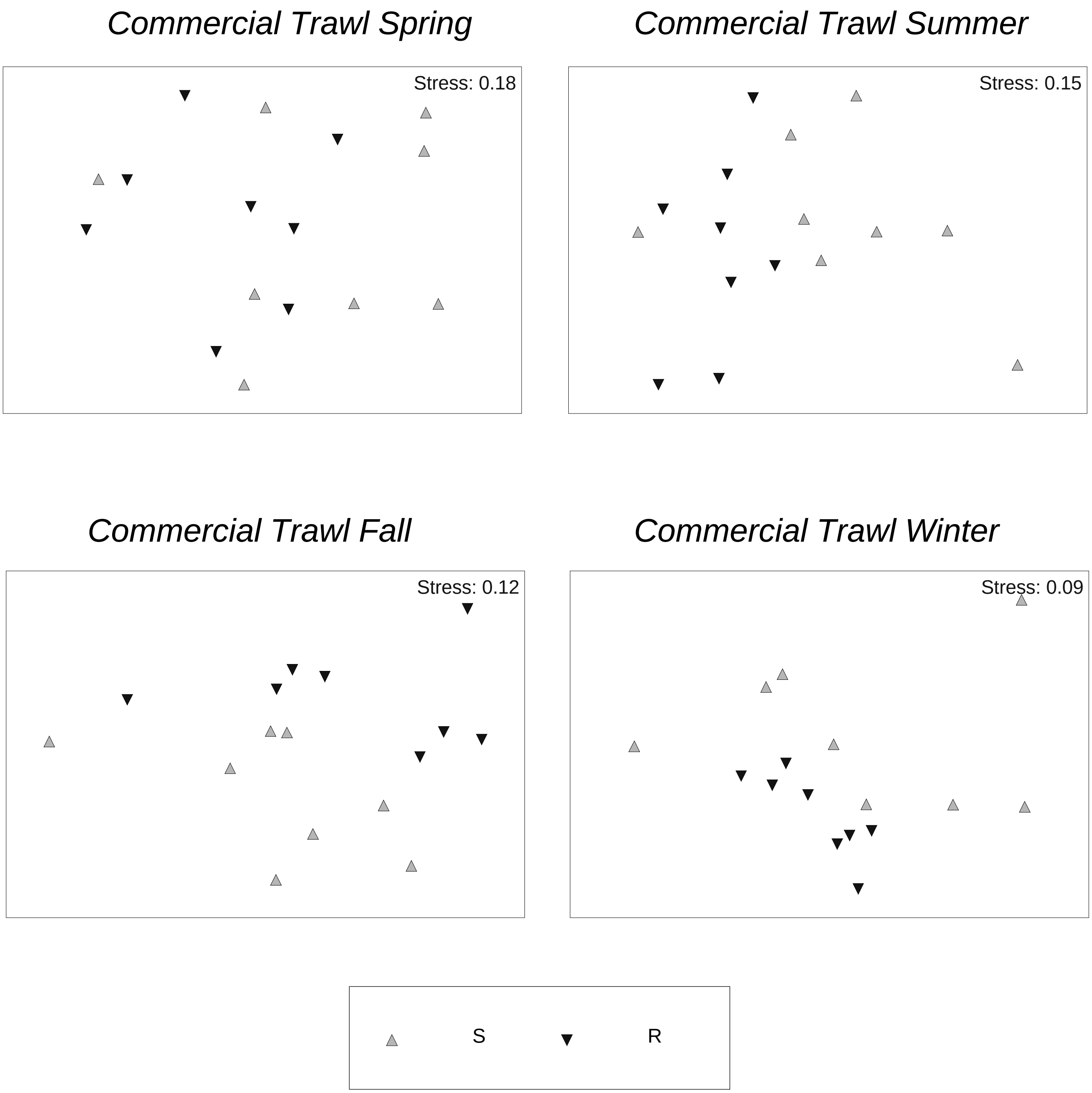


Figure 3-15. MDS ordinations of shoal (S) and reference (R) sites for the small trawl in each of four seasons.



Commercial Trawl Spring

Commercial Trawl Summer

Commercial Trawl Fall

Commercial Trawl Winter

Figure 3-16. MDS ordinations of shoal (S) and reference (R) sites for the commercial trawl and in each of four seasons.

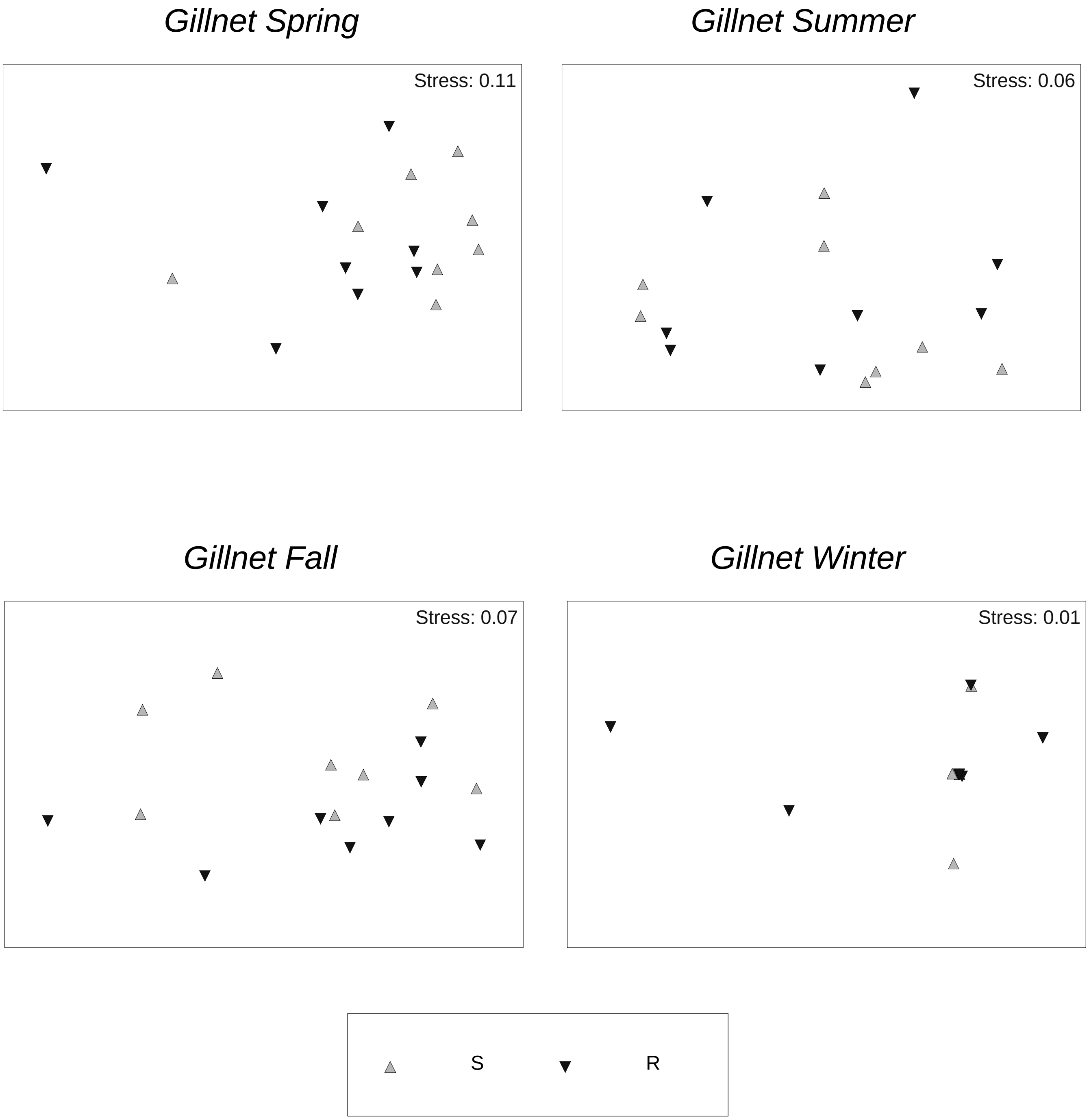


Figure 3-17. MDS ordinations of shoal (S) and reference (R) sites for gillnets in each of four seasons.

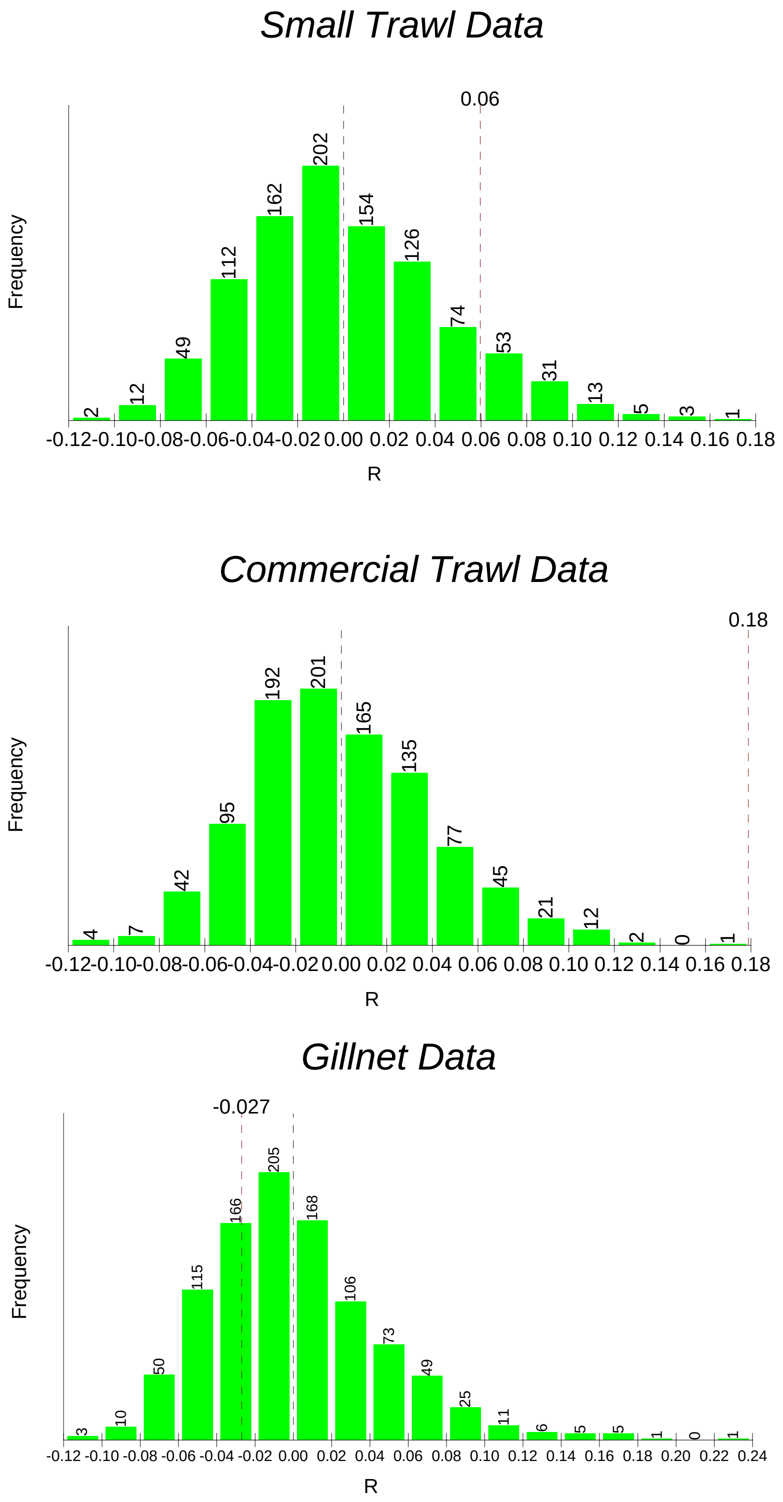
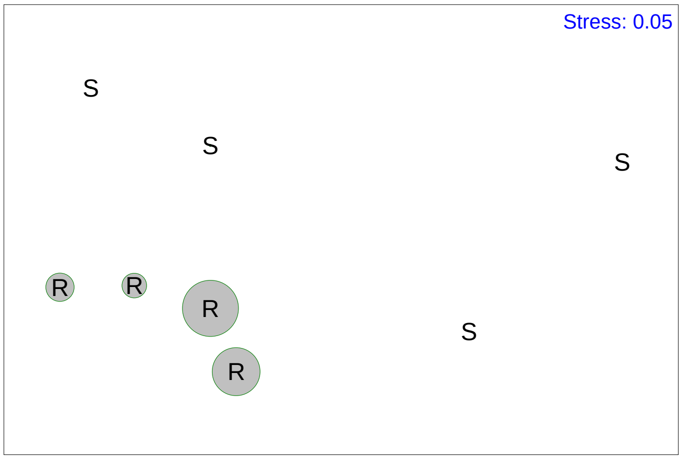


Figure 3-18. Simulated distributions of the test statistic R under the null hypothesis of no differences between shoals and reference sites. The observed value of R (averaged over the four seasons) is 0.18, 0.06, and –0.027 for each of the 25-foot trawl, 100-foot trawl, and gillnet samples, respectively.

Small Trawl, Spring + Urophycis regia



Small Trawl, Summer + Prionotus carolinus

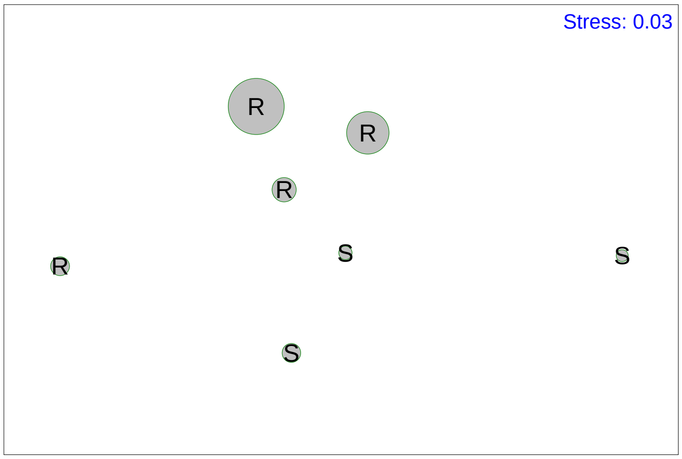


Figure 3-19. MDS ordinations of shoal (S) and reference (R) sites for the small trawl with superimposed circles representing mean CPUE of, respectively, Spotted hake (*Urophycis regia*) and Northern searobin (*Prionotus carolinus*). Differences in the size of the circles reflect differences in the magnitude of the abundance.

Commercial Trawl

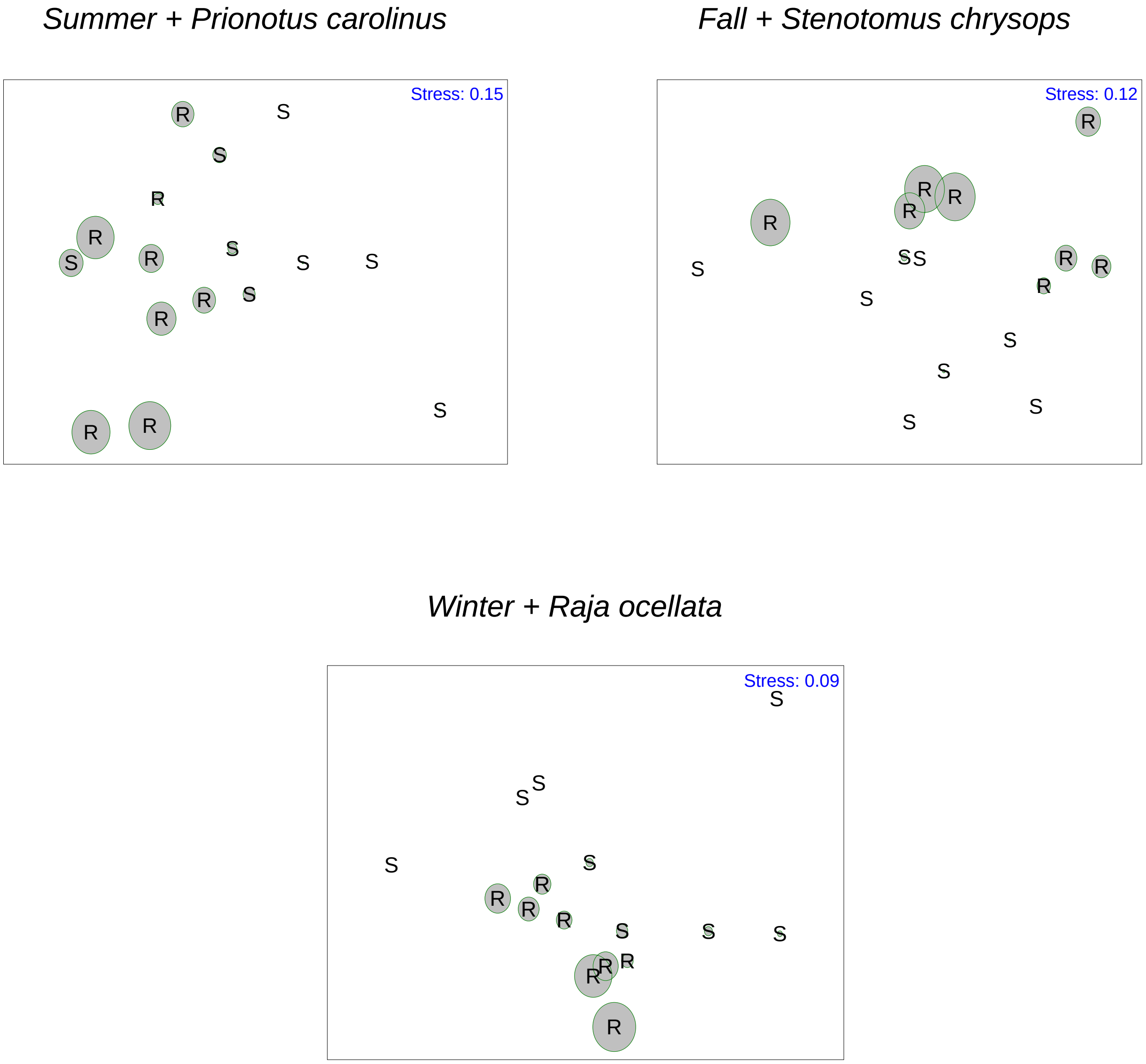


Figure 3-20. MDS ordinations of shoal (S) and reference (R) sites for the commercial trawl with superimposed circles representing mean CPUE of, respectively from top to bottom, Northern searobin (*Prionotus carolinus*), Scup (*Stenotomus chrysops*), and Winter skate (*Raja ocellata*). Differences in the size of the circles reflect differences in the magnitude of the abundance.

4.0 STATISTICAL ANALYSIS OF BIOACOUSTIC SURVEY DATA

4.1 BIOACOUSTIC SURVEY ANALYSIS

4.1.1 Bioacoustic Survey Analysis Methods

Analysis of bioacoustic data was completed using ANOVA techniques in SAS (SAS Institute 2004). Analysis variables were mean Sv (relative fish biomass in decibels) and fish density (number/10,000 m^3). The mean biomass (Sv) is calculated first by calculating the linear mean s_v using the equation:

$$S_v = \frac{\sum_{s=0}^{N_{D-1}} (\varepsilon_s \tau_s s_{vs} V_s)}{\sum_{s=0}^{N_{D-1}} (\varepsilon_s V_s)}$$

where:

s_v = The linear mean S_v for all samples in the transect D (m^2/m^3),
N_D = Number of samples in the transect D (-),
s_{vs} = The linear S_v value for sample s (m^2/m^3), and
V_s = Volume of sample s (m^3).

The mean Sv value is calculated as follows:

$$S_v = 10 \log(s_v)$$

where:

s_v = The linear mean S_v as calculated above (m^2/m^3), and
S_v = The mean S_v, Sv mean (dB re m^2/m^3)

Fish density measures are reported in units of fish/10,000 m^3. Density is calculated by:

$$\text{Density} = 10^{(Sv/10)} / 10^{(TS/10)}$$

where, Sv is the mean relative biomass (dB) and TS is the mean individual target strength (dB) within the same transect (MacLennan and Simmonds 1991). In cases where transects lacked sufficient individual targets to calculate a density estimate (fewer than 3 individuals), the mean TS for all transects at that site and survey were used to calculate density.

As noted by Foote (1980), the echo returned from a fish comes from its swim bladder, so this means that all invertebrates or fish lacking swim bladders in the survey area will not be detected acoustically. Thus, our acoustic biomass and density estimates do not include echoes associated with fish lacking a swim bladder which constitute a good portion of the catch composition from the net survey.

Attempts were made to quantify differences in fish size classes between sites using DEVIS software (Jech and Luo 2000), which is designed to partition fish densities obtained from the hydroacoustics into discrete size classes. However, too few individual targets were detected throughout the study to justify doing so. Therefore, size frequency distributions of targets satisfying the individual target criteria (individual targets) were qualitatively compared between shoals and their reference sites to gain an understanding of whether larger finfish targets were more frequently using shoals or deeper reference areas. Sizes of individual targets are measured by the hydroacoustics system in units of decibels (dB). These units are converted to approximate fish length (mm) through the use of Love’s (1977) equation as applied to a 120 kHz system. Figure 4-1 presents Love’s relationship and shows the approximate size of fish with swim bladders for a given individual target strength. Note that as fish increase in size the target strength (in dB) becomes less negative.

Analysis of acoustic data consisted of comparison of mean fish density and relative biomass across sites and seasons. As a first step, response variables (Sv, fish density) were evaluated for the effects of site, seasonal sample date, and treatment (shoal or reference site) and their interaction terms. Next, response variables were modeled as functions of site, treatment, and the interaction term (site * treatment) to evaluate whether within a site pair (e.g. Fenwick Shoal versus Fenwick Reference) there were any influences of treatment. Finally, for each site pair we evaluated the effect of treatment (shoal or reference) for each seasonal sample. This latter analysis provides the evidence of whether fish biomass or fish density, as measured with hydroacoustics, differed between each of the four shoal sites and its reference sites during the six seasonal samples. We considered a site to have higher fish use when the following occurred: (1) overall Sv or density showed a significant treatment effect for a pair of sites, or (2) where Sv or density was significantly higher in a shoal than in the reference for two or more seasonal surveys.

4.1.2 Bioacoustic Survey Analysis Results

Six seasonal surveys covering each pair of sites were completed within the study time frame. With the exception of fall 2002, all surveys were conducted at night. Overall, fish densities and mean biomass collected using hydroacoustics did not differ significantly between all shoals and reference sites combined. However, in concurrence with the net survey results, the hydroacoustic data indicated significant seasonal differences, thus demonstrating the general seasonality and transitory nature of species within the entire study area.

In general, fish densities and biomass fluctuated between sites throughout the seasonal surveys with no discernable patterns overall (Table 4-1 to 4-2). The highest densities of fish were found on Shoal B in the second summer survey, but when compared to all other sites, Fenwick Island Shoal had highest densities of fish throughout the survey (Table 4-2). Shoal D had the lowest densities of fish overall and the lowest biomass overall (Table 4-2). For all the sites, the highest mean densities and biomass were measured in the summer surveys, and the lowest densities and biomass were measured in the spring surveys. Differences between individual shoals and their reference sites were found in many seasons and some patterns are evident within site pairs (Figure 4-2 to 4-9). In particular, Fenwick Island Shoal and Weaver Shoal exhibited higher densities and biomass when compared to their reference pairs, and when tests were significant they favored higher estimates at these shoals the majority of the time. The other two shoals and reference sites did not exhibit any consistent pattern of higher estimates throughout the study. Seasonal descriptions of all measures for each shoal as it compares to its reference site is presented here.

Shoal B

Differences between fish densities and biomass at Shoal B when compared to its reference were mixed and no consistent patterns were evident. During fall 2002 and summer 2004 surveys the reference had significantly higher relative biomass than Shoal B (Figure 4-2). Only in fall 2003 was fish biomass higher at the shoal when compared to its reference site. The only significant difference in density also occurred during fall 2003 when Shoal B fish density exceeded Shoal B Reference (Figure 4-3).

Despite few targets at Shoal B, the size ranges and distributions of sizes appeared similar between the shoal and its reference area (Figures 4-10 to 4-12). In spring surveys, targets ranged from -50 to -33 dB (Figure 4-10). During the summer surveys, size distributions were skewed towards small sizes, but were slightly larger in summer 03 at the reference than the shoal (Figure 4-11). Fall distributions differed between years with generally smaller targets in fall 03 than fall 02 (Figure 4-12). Fall 02 distributions at the reference site were widely distributed with multiple modes at -48 dB (~ 50 mm), -43 dB (~80 mm), -39 dB (~125 mm), -37 dB (~175 mm), -33 dB (~290 mm), and -27 dB (~500 mm). This multimodal distribution suggests a diverse size and/or species assemblage at the reference site during fall 2002.

Shoal D

The Shoal D and its reference site showed significant differences in Sv and density between one another, with a split result. For relative biomass Shoal D was significantly higher in spring 03 and fall 03, but was significantly lower than the reference during both summer surveys (Figure 4-4). Fish density was significantly higher on the shoal during fall 03, but was lower during summer 03 (Figure 4-5).

There were only very minor differences in target strength distributions between Shoal D and its reference in any surveys within a season (Figures 4-13 to 4-15). Shoal D and its reference site had very few targets during spring sampling (Figure 4-13). All targets were small (< 120 mm or -39 dB). In summer the distributions between the shoal and reference site were very similar (Figure 3-14). Fish up to -29 dB (> 390 mm) were found on both sites with the majority of fish under -44 dB or about 70 mm. In fall, larger targets comprised more of the frequency at Shoal D and its reference (Figure 4-15). Ranges in target strength were similar between the shoal and reference, although the fall 03 survey was very limited in numbers of targets.

Fenwick Island Shoal

Relative fish biomass showed a seasonal pattern and indicated greater fish use of Fenwick Shoal than the reference (Figure 4-6). Fish biomass was lowest in spring and generally highest in summer surveys. In fall 02 the reference had significantly higher biomass than the shoal. However, in summer 03, fall 03, and spring 04, Fenwick Shoal had significantly higher fish biomass than the reference. Fish densities tended to be low in both spring surveys at Fenwick Shoal and its reference with higher values in summer and fall. However, fish density was only significantly different in two surveys (Figure 4-7). In fall 02 fish density was higher in the reference and in summer 03 fish density was higher at Fenwick Shoal.

Size ranges and distributions between Fenwick Shoal and the reference were generally similar except during fall (Figures 4-16 to 4-18). In spring most fish were less than -42 dB (~80 mm) although targets up to -32 dB was detected (Figure 4-16). Distributions showed two peaks in summer 03 at -48 and -42 dB. Summer 04 distributions ranged from -49 to -31 dB (Figure 4-17). In fall 02 few targets were detected at Fenwick Shoal (Figure 4-18). The reference site showed a multimodal distribution ranging to -27 dB in fall 02, but was mostly smaller fish (< -43 dB) in fall 03. The shoal had a greater number of larger targets in fall 03 than the reference suggesting greater use of the shoal by larger fish in fall 03. The opposite was observed at the Fenwick Reference where larger fish were recorded at the site in fall 02.

Weaver Shoal

The relative biomass between Weaver Shoal and the reference site was significantly different during three surveys (Figure 4-8). On two occasions, spring 03 and summer 03, the relative biomass was higher on the shoal than on the reference and once (summer 04) the reference was significantly higher than the shoal. Fish density was significantly higher at Weaver Shoal than the reference during the fall 02 and summer 03 surveys (Figure 4-9).

During spring, the mode of target strengths at Weaver Shoal and reference were similar and dominated by smaller (-45 dB) targets, approximately 60-65 mm in length (Figure 4-19). Larger targets up to 350 mm (-31 dB) were detected at both sites. However, there does not appear to be anything in the length data that would suggest differences in size classes or species using the two sites.

During summer, size distributions were similar between the two sites and the two surveys (Figure 4-20). Most fish were small (< 117 mm or -40 dB), with peaks in modes at -49 to -48 dB in both years. However, at the shoal a secondary modal peak at -42 to -41 dB was apparent in both years suggesting some differences in abundance of species in the 100-125 mm size range that may favor the shoal over the reference site.

The fall surveys appear to show a higher use of larger targets at both sites (Figure 4-21). Targets extended from -50 to -25 dB on the shoal and -50 to -21 dB on the reference site. Most targets fell below -44 dB (75 mm) on both sites in fall 03. However, in fall 02 the reference site had very few targets in this smaller size group. Large targets were more common in fall02 than fall 03 at Weaver Shoal, a pattern similar to the reference site.

Table 4-1. Mean biomass (expressed as backscattering coefficient Sv in dB) and confidence limits for all acoustic transects conducted during sampling at four shoals and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004.

Date/ Survey	**Mean**	**95%CL**	**Mean**	**95%CL**	**Date/ Survey**	**Mean**	**95%CL**	**Mean**	**95%CL**
	Weaver Shoal		**Reference**			**Shoal D**		**Reference**	
Fall 2002	-57.8	3.4	-62.7	4.7	Fall 2002	-72.9	7.7	-67.3	11.0
Spring 2003	-74.3	7.5	-91.3	1.4	Spring 2003	-85.7	3.4	-91.8	5.1
Summer 2003	-59.2	1.5	-64.4	1.2	Summer 2003	-76.6	2.3	-61.8	2.2
Fall 2003	-69.1	5.7	-73.6	2.0	Fall 2003	-75.9	4.4	-81.9	2.3
Spring 2004	-77.7	4.6	-78.3	3.6	Spring 2004	-86.6	3.7	-88.2	5.2
Summer 2004	-62.4	0.8	-59.8	2.2	Summer 2004	-62.6	1.2	-59.0	0.9
Sum	**-400.5**		**-430.0**		**Sum**	**-460.2**		**-450.0**	
	Shoal B		**Reference**			**Fenwick Shoal**		**Reference**	
Fall 2002	-72.9	5.9	-58.3	9.0	Fall 2002	-69.3	10.4	-54.7	2.9
Spring 2003	-79.8	2.9	-83.6	5.1	Spring 2003	-78.5	6.2	-78.4	5.2
Summer 2003	-63.9	5.3	-63.8	1.5	Summer 2003	-57.8	0.6	-63.1	1.2
Fall 2003	-70.6	4.0	-78.1	1.9	Fall 2003	-64.4	6.1	-73.2	2.0
Spring 2004	-92.8	5.8	-91.0	2.1	Spring 2004	-70.9	5.6	-87.2	8.5
Summer 2004	-59.6	0.7	-58.4	0.8	Summer 2004	-60.7	3.9	-59.6	0.7
Sum	**-439.5**		**-433.2**		**Sum**	**-401.6**		**-416.1**	

Table 4-2. Mean fish density per 10,000 m3 and confidence limits and confidence limits for all acoustic transects conducted during sampling at four shoals and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004

Date/ Survey	**Mean**	**95%CL**	**Mean**	**95%CL**	**Date/ Survey**	**Mean**	**95%CL**	**Mean**	**95%CL**
	Weaver Shoal		**Reference**			**Shoal D**		**Reference**	
Fall 2002	208.2	143.4	35.6	49.3	Fall 2002	1.6	3.1	76.0	185.7
Spring 2003	19.6	34.3	0.8	0.3	Spring 2003	3.2	2.6	1.2	1.5
Summer 2003	382.6	89.8	169.2	33.3	Summer 2003	6.2	2.9	241.2	92.8
Fall 2003	198.5	252.3	28.8	14.9	Fall 2003	11.7	9.8	0.6	0.3
Spring 2004	4.3	2.4	7.2	4.6	Spring 2004	0.7	0.6	0.6	0.5
Summer 2004	206.1	53.2	370.5	178.0	Summer 2004	230.5	88.1	205.2	48.2
Sum	**1019.2**		**612.1**		**Sum**	**253.9**		**524.8**	
	Shoal B		**Reference**			**Fenwick Shoal**		**Reference**	
Fall 2002	14.7	21.3	515.3	544.7	Fall 2002	89.4	148.9	359.8	265.4
Spring 2003	2.1	2.2	0.6	0.6	Spring 2003	41.3	85.6	2.5	2.3
Summer 2003	226.7	244.1	108.8	42.3	Summer 2003	544.9	77.6	227.7	57.5
Fall 2003	63.5	53.9	9.6	6.0	Fall 2003	509.4	648.3	28.0	13.4
Spring 2004	0.3	0.4	0.3	0.4	Spring 2004	50.9	61.9	4.7	6.0
Summer 2004	598.2	130.6	533.9	171.8	Summer 2004	194.3	77.4	220.1	60.5
Sum	**905.6**		**1168.5**		**Sum**	**1430.1**		**842.9**	

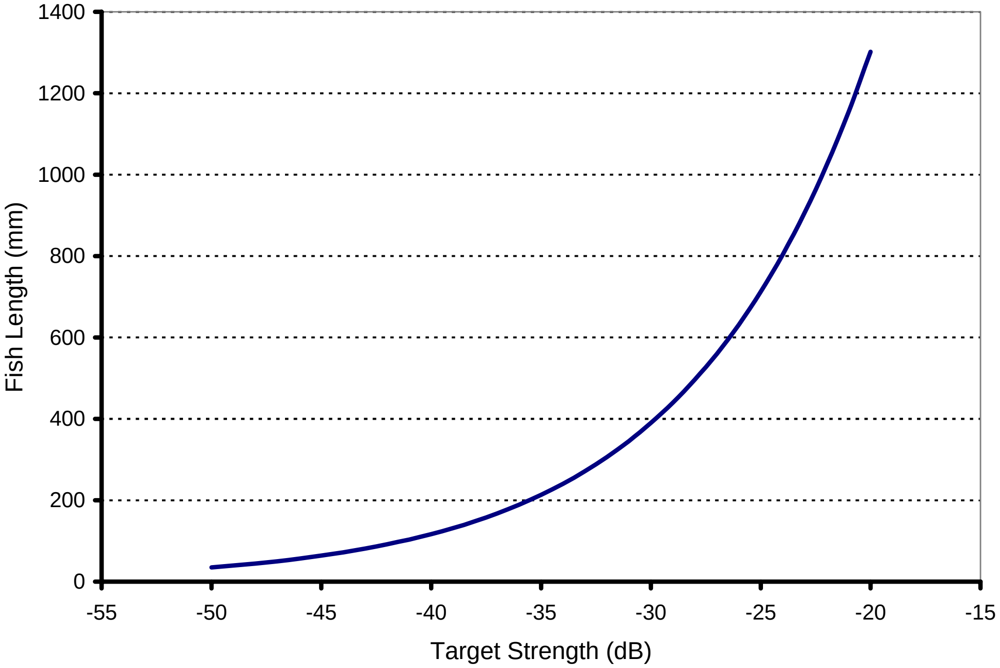


Figure 4-1. The relationship of individual target strength of acoustic targets (dB) to fish length (mm) for fishes with swim bladders as described by Love (1977) for many species of fish at 120 kHz frequency.

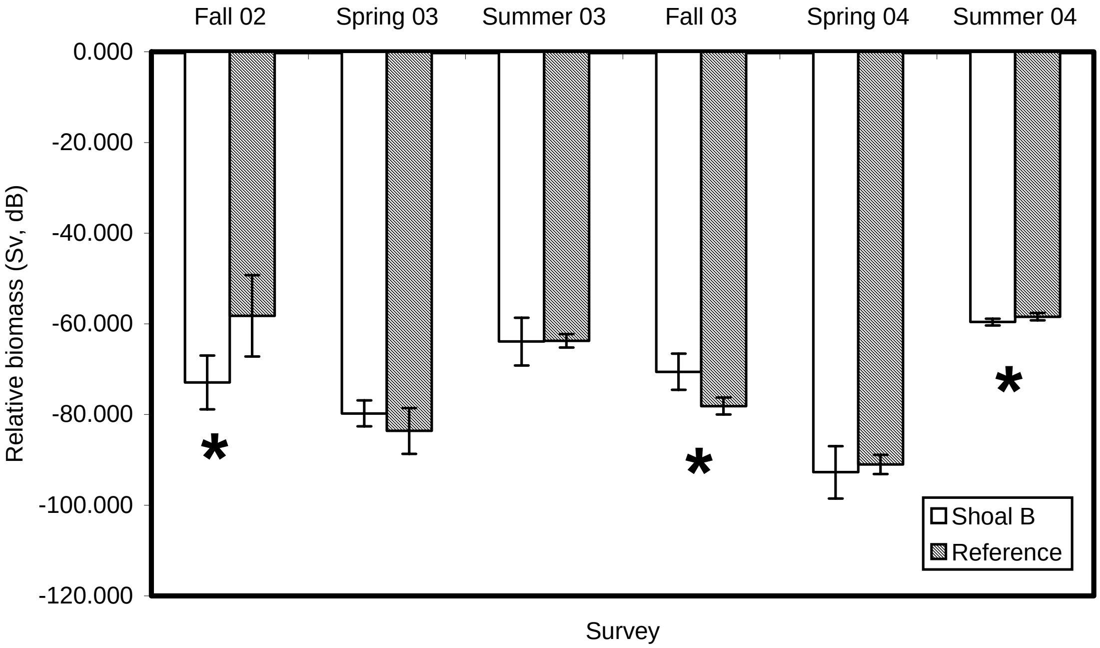


Figure 4-2. Relative biomass (Sv in dB) of fish detected with a 120 kHz hydroacoustic split beam system at Shoal B (open bars) and its reference site (diagonal striped bars) for each of 6 seasonal surveys. Error bars represent 95% confidence intervals about the mean. An asterisk (*) denotes a significant difference between the shoal and its reference in a given survey.

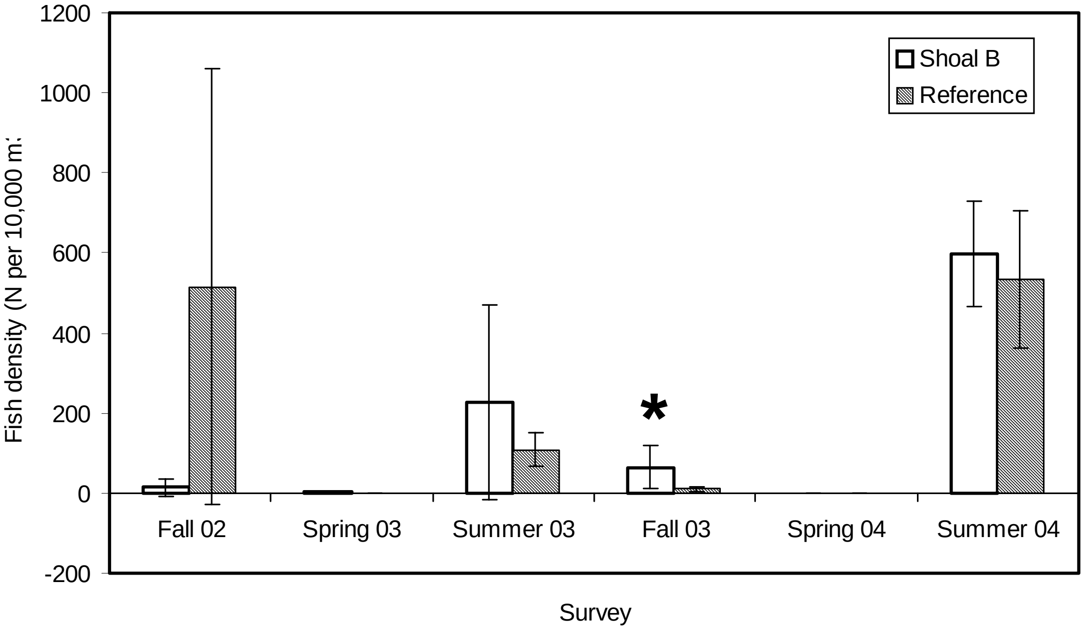


Figure 4-3. Fish density (N per 10,000 m^3) of fish detected with a 120 kHz hydroacoustic split beam system at Shoal B (open bars) and its reference site (diagonal striped bars) for each of 6 seasonal surveys. Error bars represent 95% confidence intervals about the mean. An asterisk (*) denotes a significant difference between the shoal and its reference in a given survey.

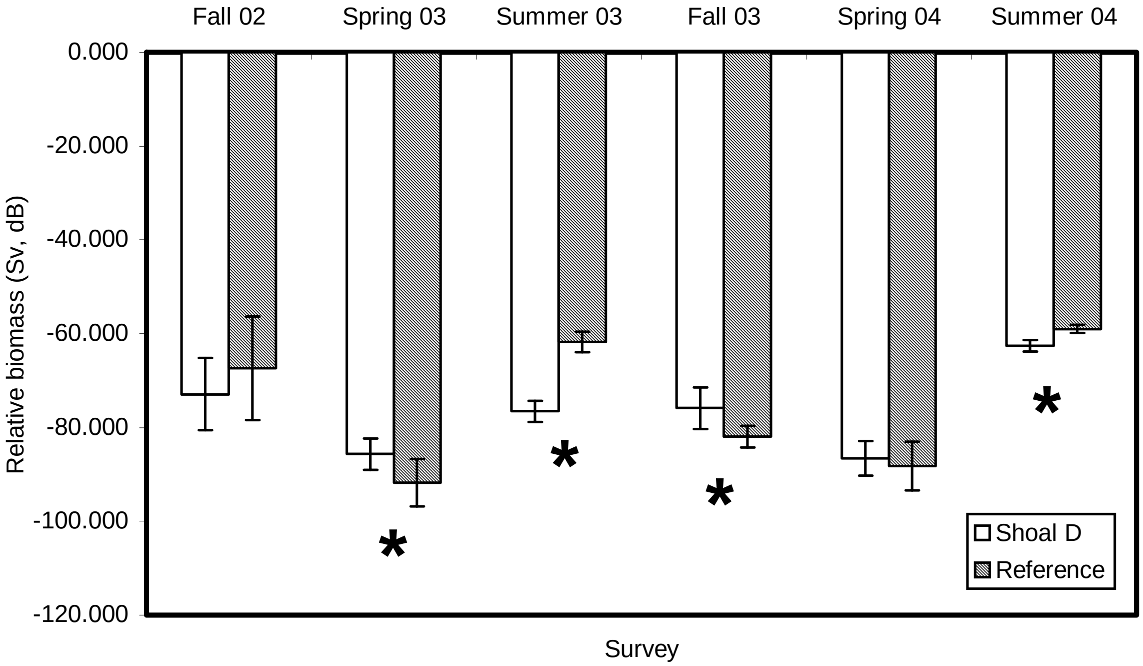


Figure 4-4. Relative biomass (Sv in dB) of fish detected with a 120 kHz hydroacoustic split beam system at Shoal D (open bars) and its reference site (diagonal striped bars) for each of 6 seasonal surveys. Error bars represent 95% confidence intervals about the mean. An asterisk (*) denotes a significant difference between the shoal and its reference in a given survey.

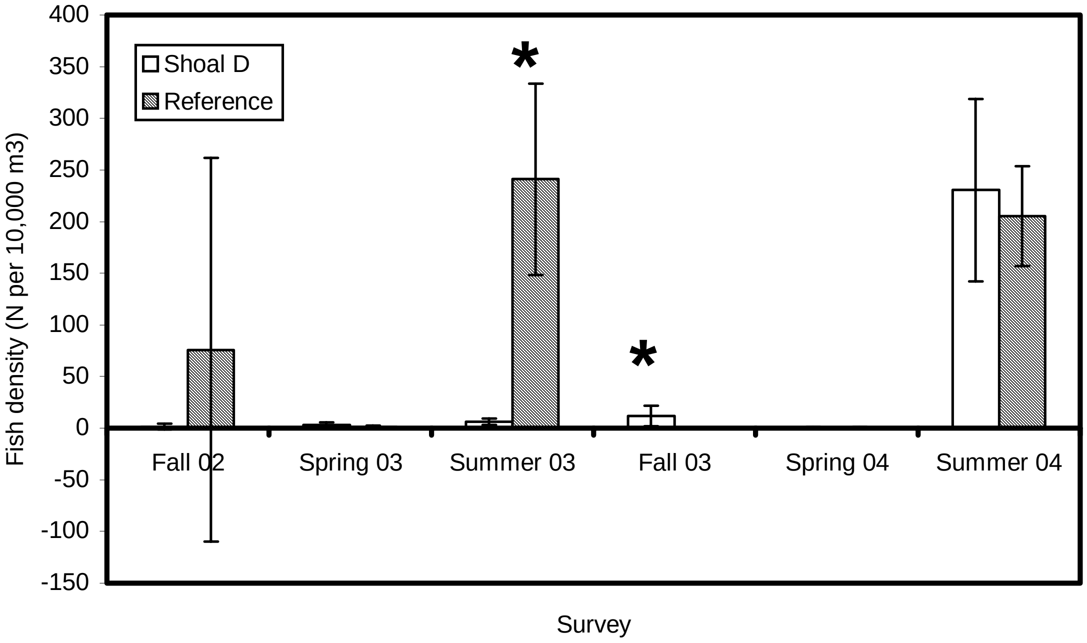


Figure 4-5. Fish density (N per 10,000 m^3) of fish detected with a 120 kHz hydroacoustic split beam system at Shoal D (open bars) and its reference site (diagonal striped bars) for each of 6 seasonal surveys. Error bars represent 95% confidence intervals about the mean. An asterisk (*) denotes a significant difference between the shoal and its reference in a given survey.

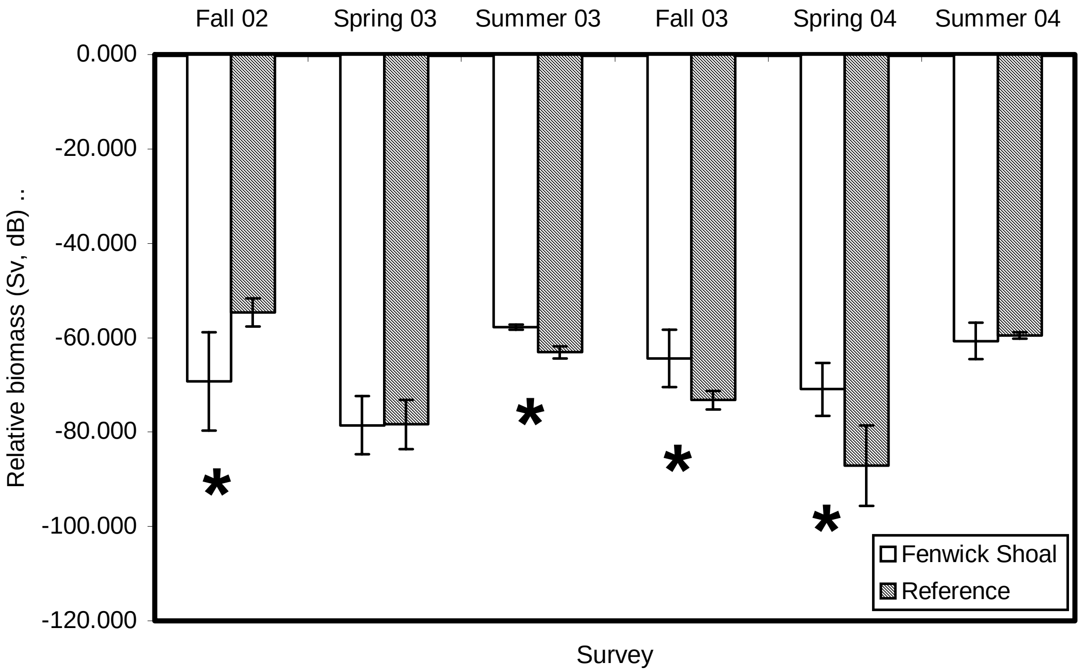


Figure 4-6. Relative biomass (Sv in dB) of fish detected with a 120 kHz hydroacoustic split beam system at Fenwick Shoal (open bars) and its reference site (diagonal striped bars) for each of 6 seasonal surveys. Error bars represent 95% confidence intervals about the mean. An asterisk (*) denotes a significant difference between the shoal and its reference in a given survey.

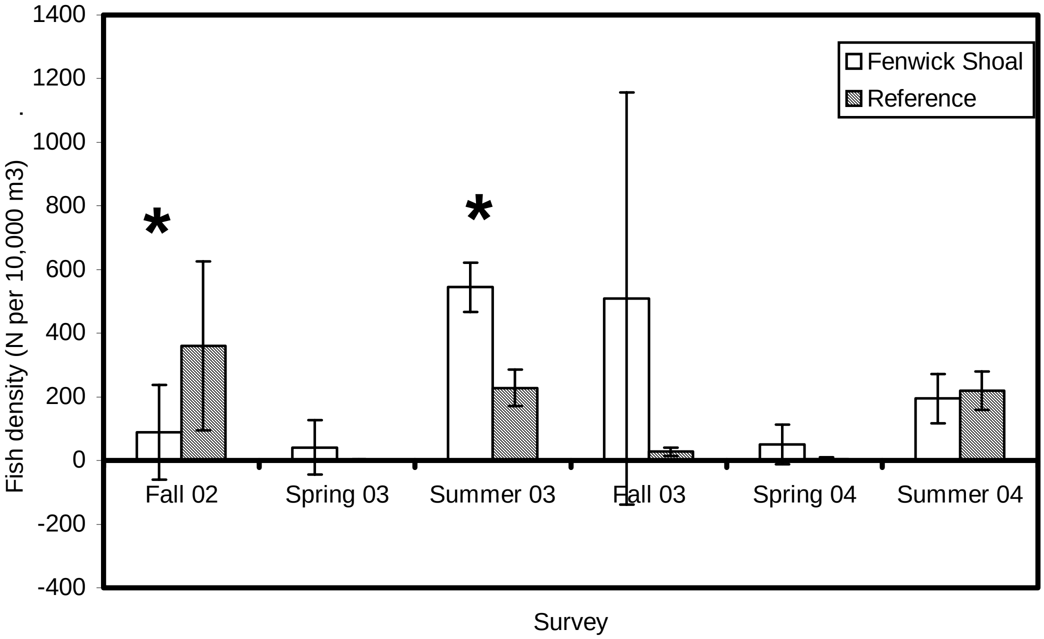


Figure 4-7. Fish density (N per 10,000 m^3) of fish detected with a 120 kHz hydroacoustic split beam system at Fenwick Shoal (open bars) and its reference site (diagonal striped bars) for each of 6 seasonal surveys. Error bars represent 95% confidence intervals about the mean. An asterisk (*) denotes a significant difference between the shoal and its reference in a given survey.

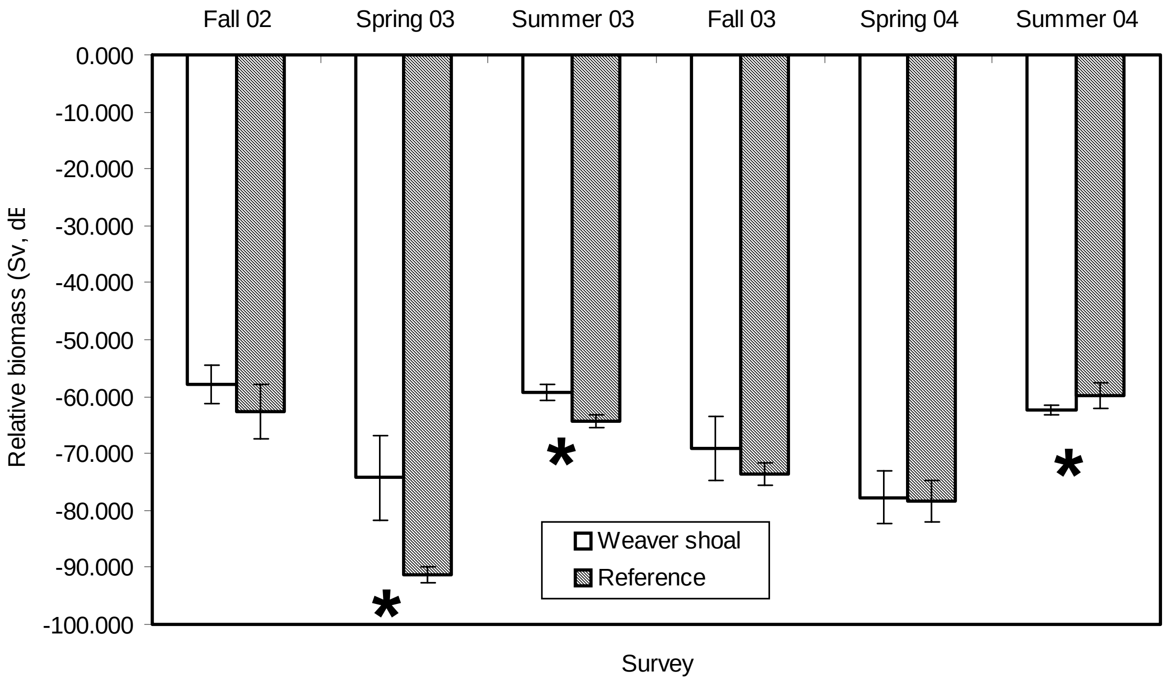


Figure 4-8. Relative biomass (Sv in dB) of fish detected with a 120 kHz hydroacoustic split beam system at Weaver Shoal (open bars) and its reference site (diagonal striped bars) for each of 6 seasonal surveys. Error bars represent 95% confidence intervals about the mean. An asterisk (*) denotes a significant difference between the shoal and its reference in a given survey.

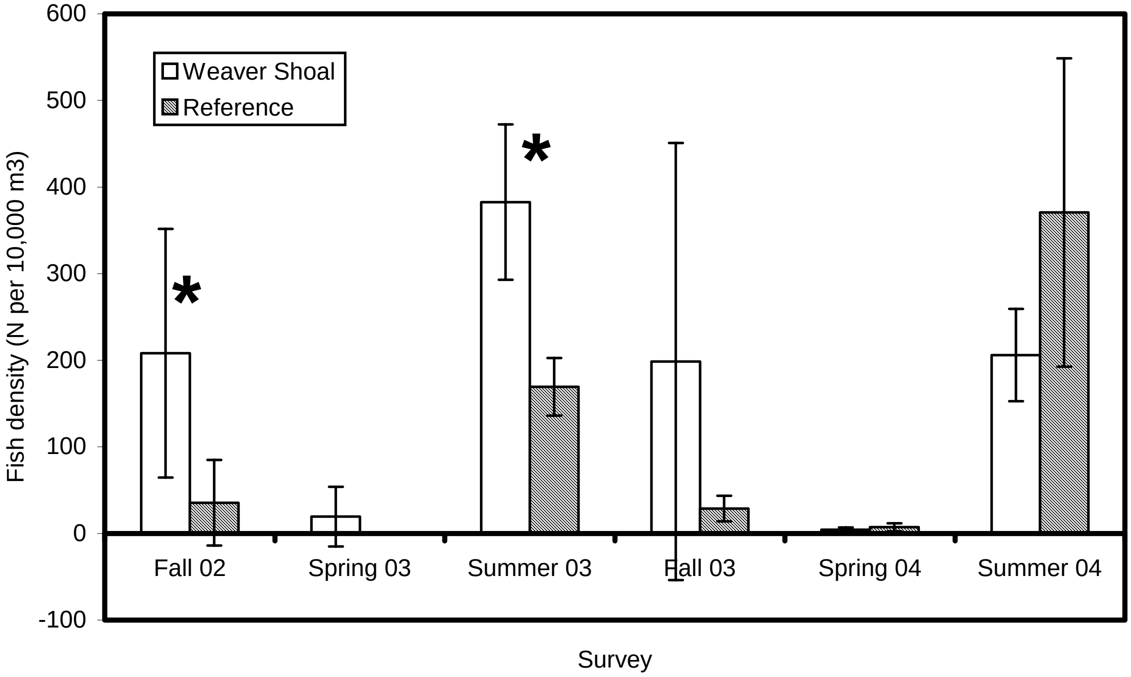
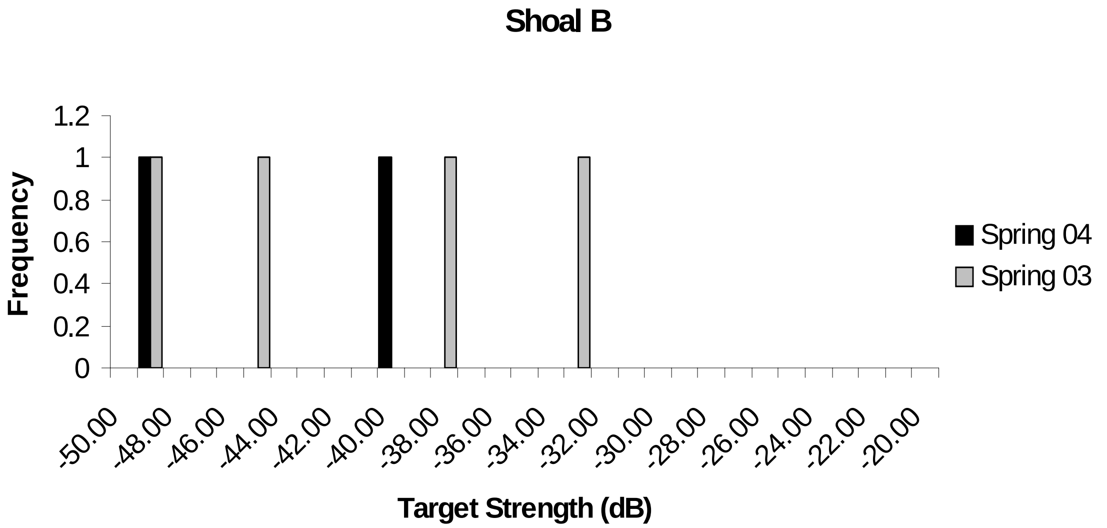


Figure 4-9. Fish density (N per 10,000 m^3) of fish detected with a 120 kHz hydroacoustic split beam system at Weaver Shoal (open bars) and its reference site (diagonal striped bars) for each of 6 seasonal surveys. Error bars represent 95% confidence intervals about the mean. An asterisk (*) denotes a significant difference between the shoal and its reference in a given survey.



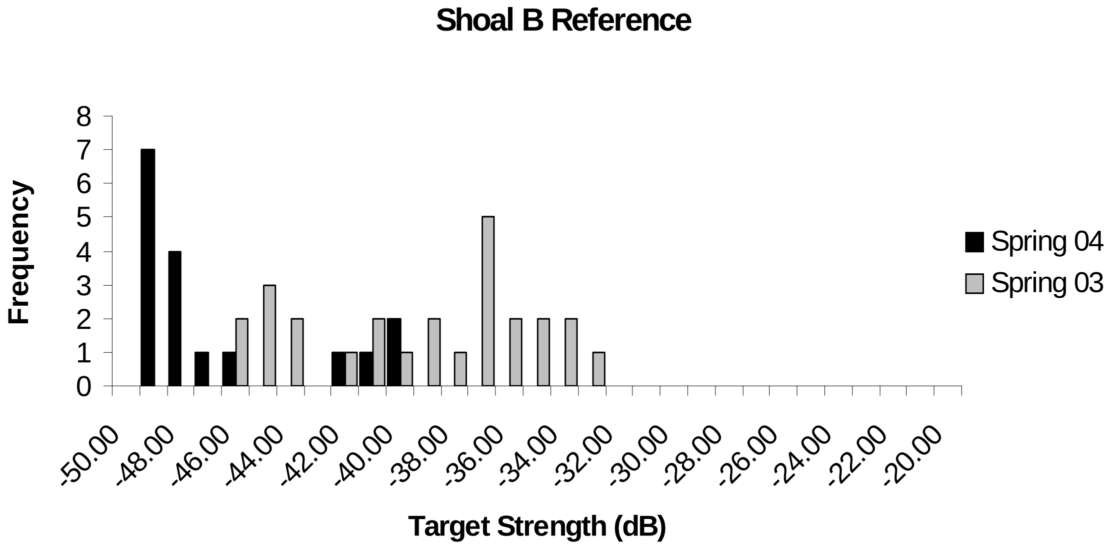
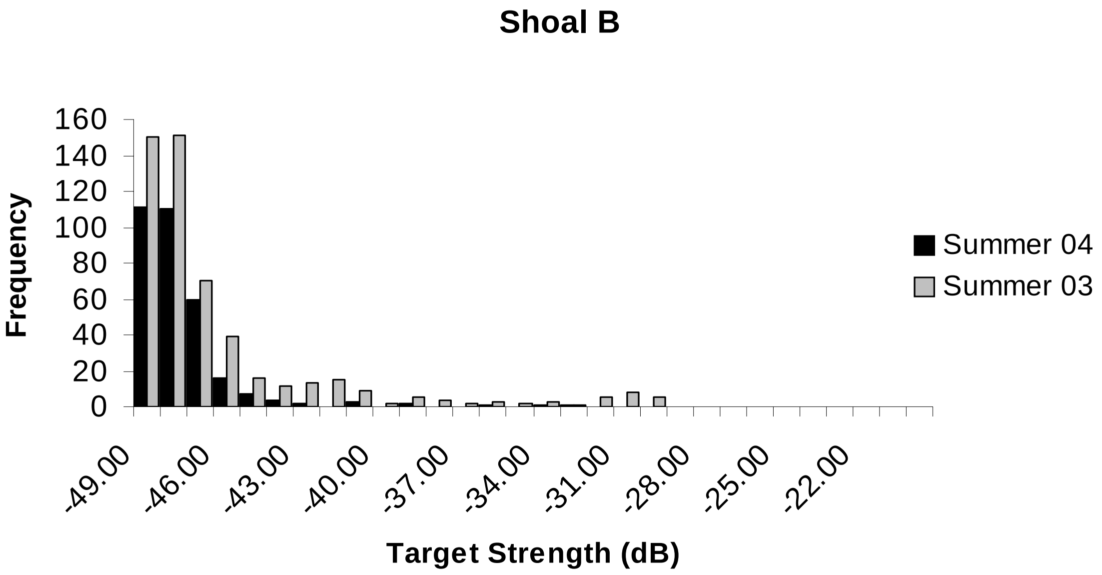


Figure 4-10. Seasonal size frequency distribution of fish satisfying individual target criteria from hydroacoustic transects (combined) during spring 03 and spring 04 sampling at Shoal B site and its reference area. Fish sizes are in decibels as measured with the acoustics. Using Love's (1977) equation, these target strengths equate roughly to the following: -50 dB is 35.0 mm; -45 dB is 63.9 mm; -40 dB is 116.8 mm; -35 dB is 213.4 mm; -30 dB is 389.9 mm; -25 dB is 712.4 mm; and –20 dB is 1301.7 mm.



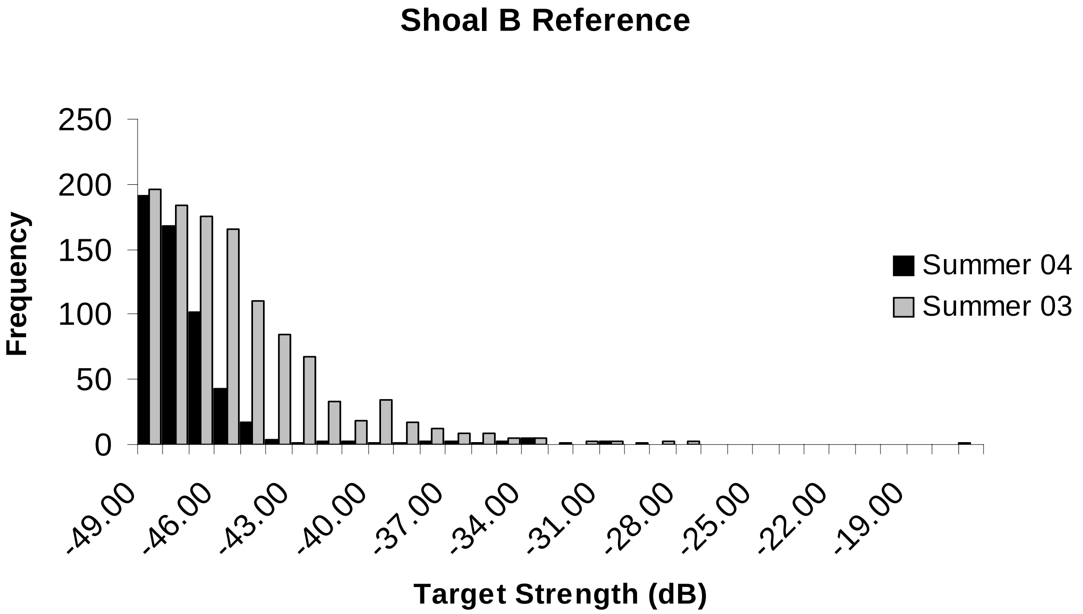
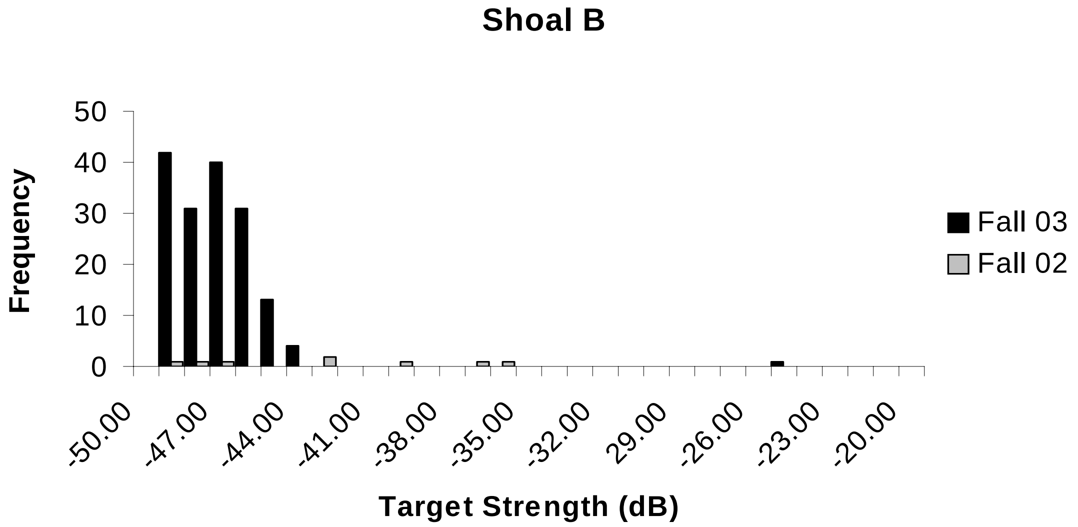


Figure 4-11. Seasonal size frequency distribution of fish satisfying individual target criteria from hydroacoustic transects (combined) during summer 03 and summer 04 sampling Shoal B site and its reference area. Fish sizes are in decibels as measured with the acoustics. Using Love's (1977) equation, these target strengths equate roughly to the following: -50 dB is 35.0 mm; -45 dB is 63.9 mm; -40 dB is 116.8 mm; -35 dB is 213.4 mm; -30 dB is 389.9 mm; -25 dB is 712.4 mm; and –20 dB is 1301.7 mm.



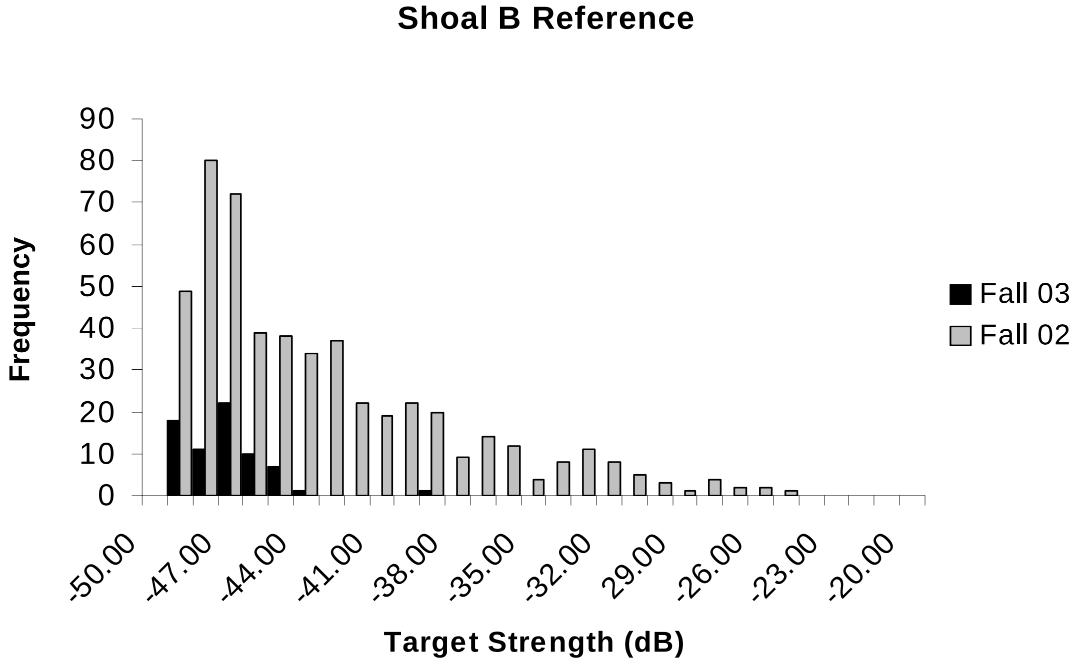
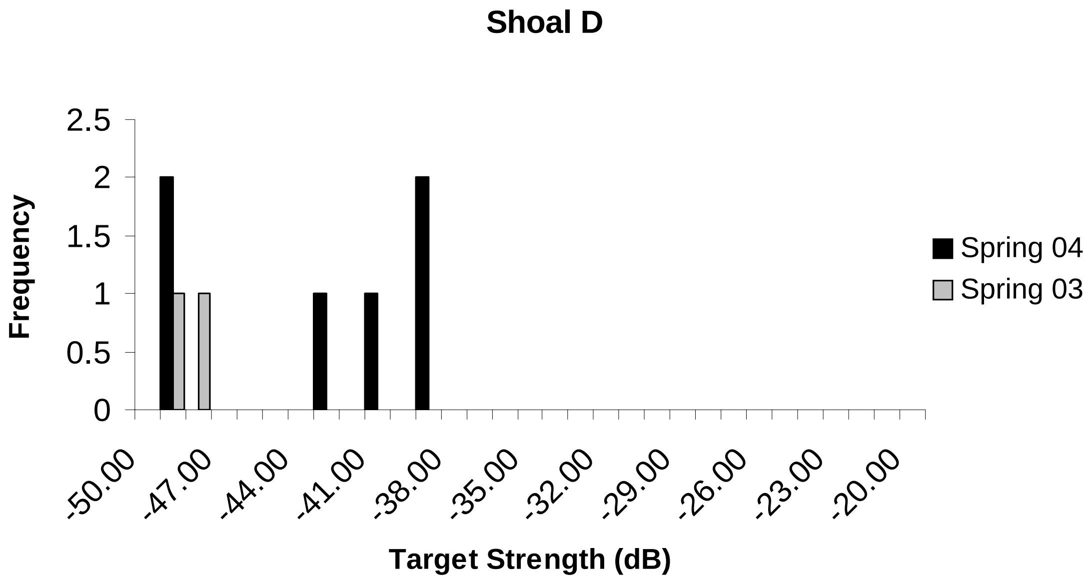


Figure 4-12. Seasonal size frequency distribution of fish satisfying individual target criteria from hydroacoustic transects (combined) during fall 02 and fall 03 sampling at Shoal B site and its reference area. Fish sizes are in decibels as measured with the acoustics. Using Love's (1977) equation, these target strengths equate roughly to the following: -50 dB is 35.0 mm; -45 dB is 63.9 mm; -40 dB is 116.8 mm; -35 dB is 213.4 mm; -30 dB is 389.9 mm; -25 dB is 712.4 mm; and –20 dB is 1301.7 mm.



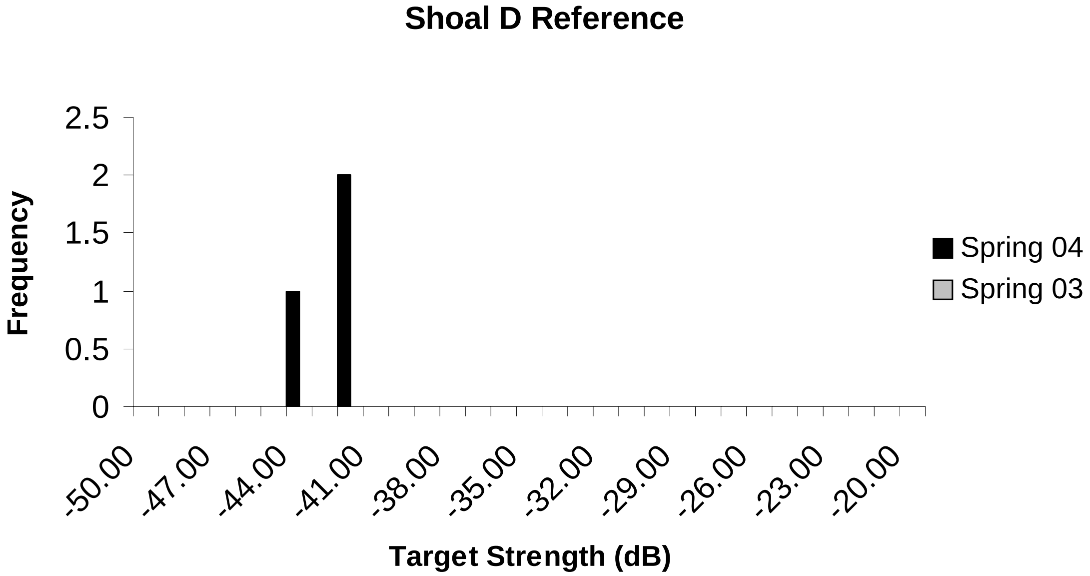
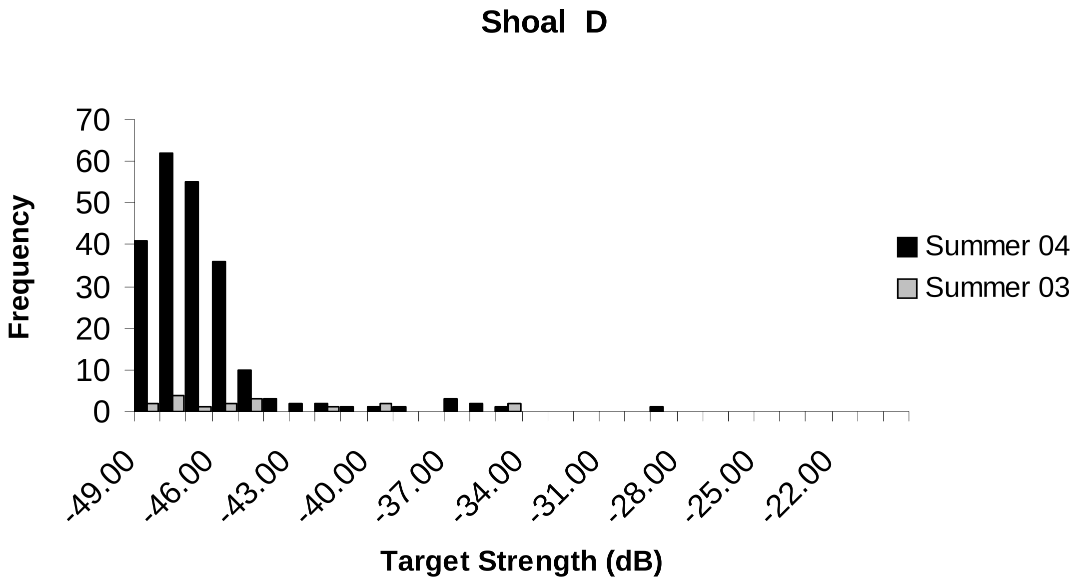


Figure 4-13. Seasonal size frequency distribution of fish satisfying individual target criteria from hydroacoustic transects (combined) during spring 03and spring 04 sampling at Shoal D site and its reference area. Fish sizes are in decibels as measured with the acoustics. Using Love's (1977) equation, these target strengths equate roughly to the following: -50 dB is 35.0 mm; -45 dB is 63.9 mm; -40 dB is 116.8 mm; -35 dB is 213.4 mm; -30 dB is 389.9 mm; -25 dB is 712.4 mm; and –20 dB is 1301.7 mm.



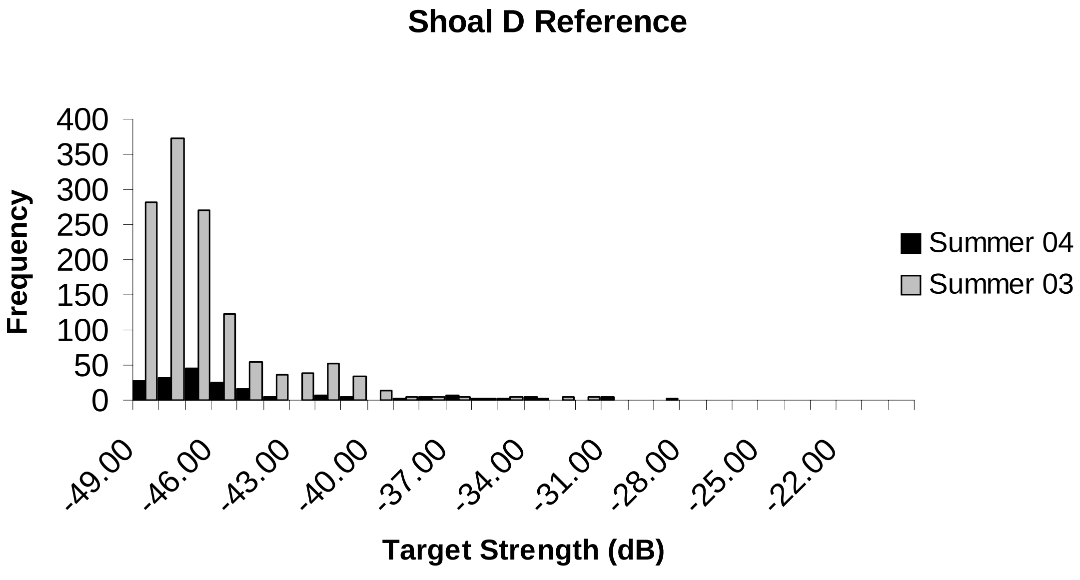
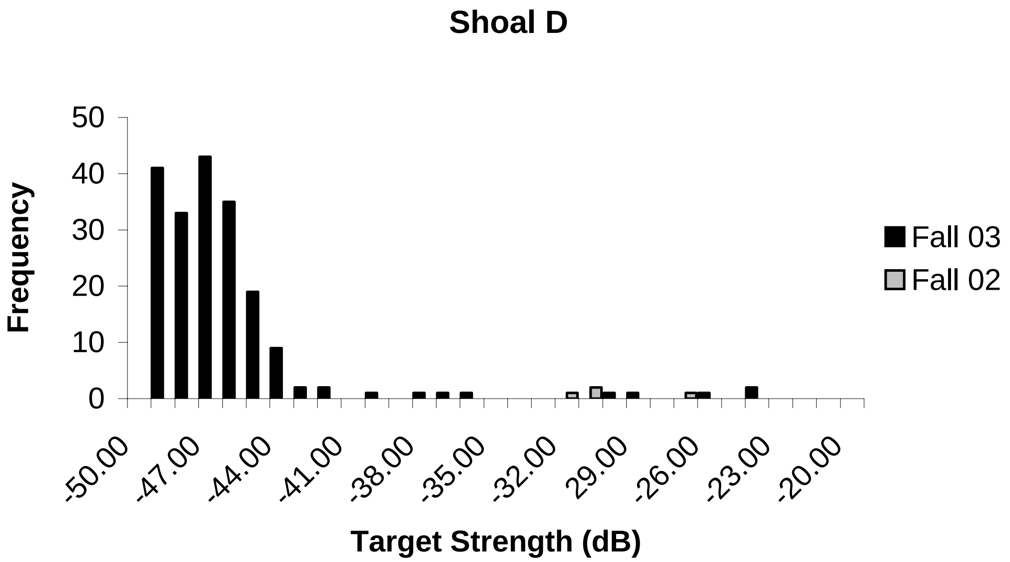


Figure 4-14. Seasonal size frequency distribution of fish satisfying individual target criteria from hydroacoustic transects (combined) during summer 03 and summer 04 sampling at Shoal D site and its reference area. Fish sizes are in decibels as measured with the acoustics. Using Love's (1977) equation, these target strengths equate roughly to the following: -50 dB is 35.0 mm; -45 dB is 63.9 mm; -40 dB is 116.8 mm; -35 dB is 213.4 mm; -30 dB is 389.9 mm; -25 dB is 712.4 mm; and –20 dB is 1301.7 mm.



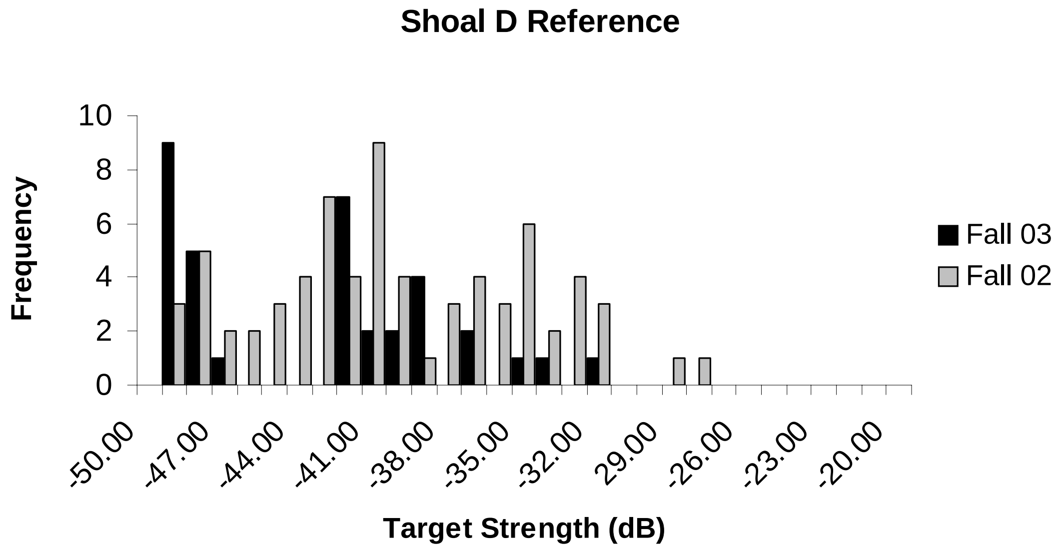
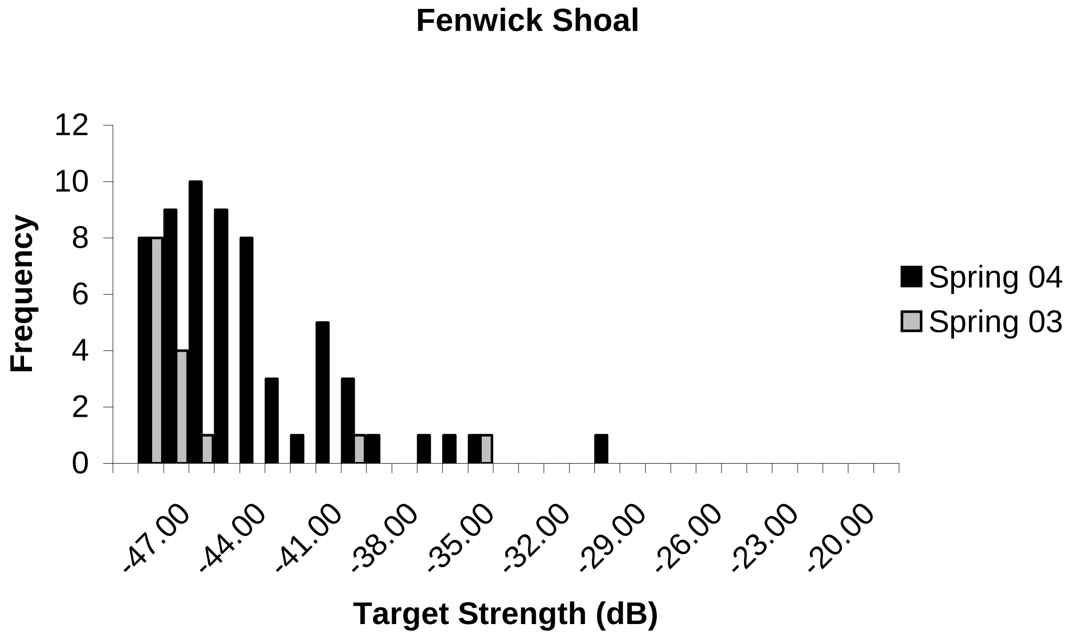


Figure 4-15. Seasonal size frequency distribution of fish satisfying individual target criteria from hydroacoustic transects (combined) during fall 02 and fall 03 sampling at Shoal D site and its reference area. Fish sizes are in decibels as measured with the acoustics. Using Love’s (1977) equation, these target strengths equate roughly to the following: -50 dB is 35.0 mm; -45 dB is 63.9 mm; -40 dB is 116.8 mm; -35 dB is 213.4 mm; -30 dB is 389.9 mm; -25 dB is 712.4 mm; and –20 dB is 1301.7 mm.



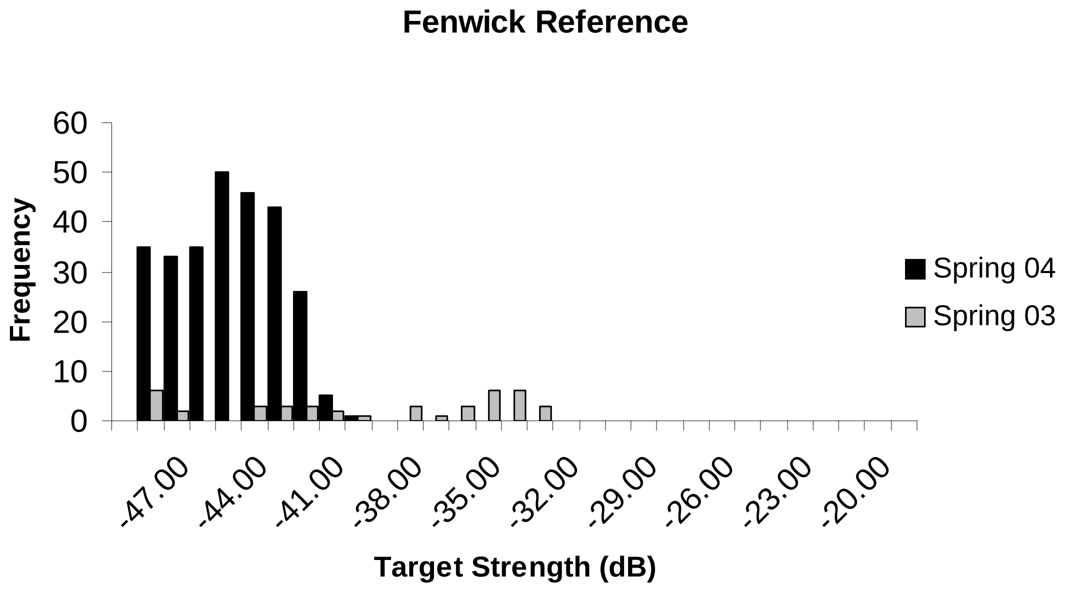
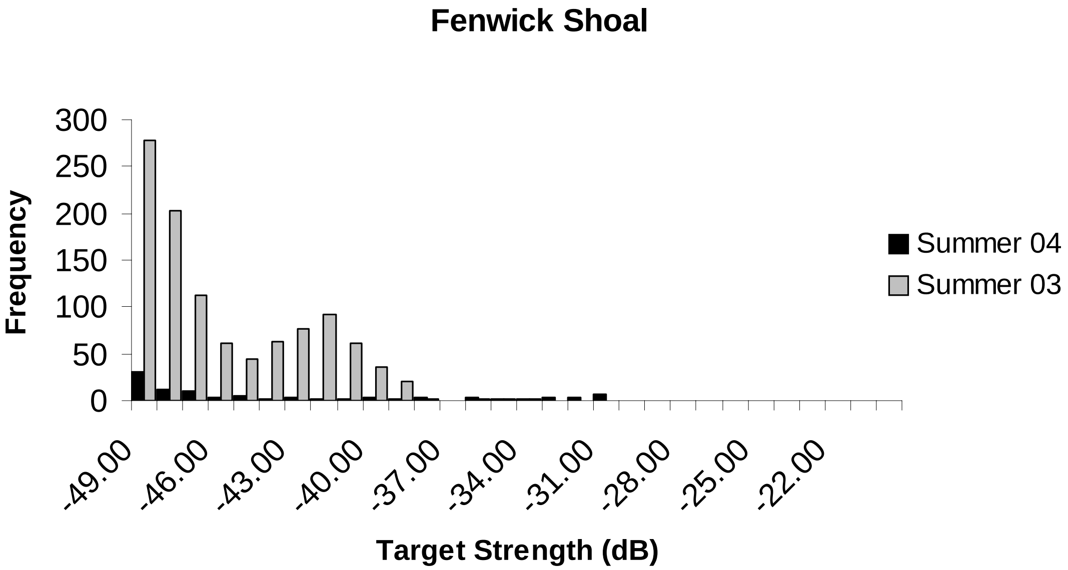


Figure 4-16. Seasonal size frequency distribution of fish satisfying individual target criteria from hydroacoustic transects (combined) during spring 03 and spring 04 sampling at Fenwick Shoal site and its reference area. Fish sizes are in decibels as measured with the acoustics. Using Love's (1977) equation, these target strengths equate roughly to the following: -50 dB is 35.0 mm; -45 dB is 63.9 mm; -40 dB is 116.8 mm; -35 dB is 213.4 mm; -30 dB is 389.9 mm; -25 dB is 712.4 mm; and –20 dB is 1301.7 mm.



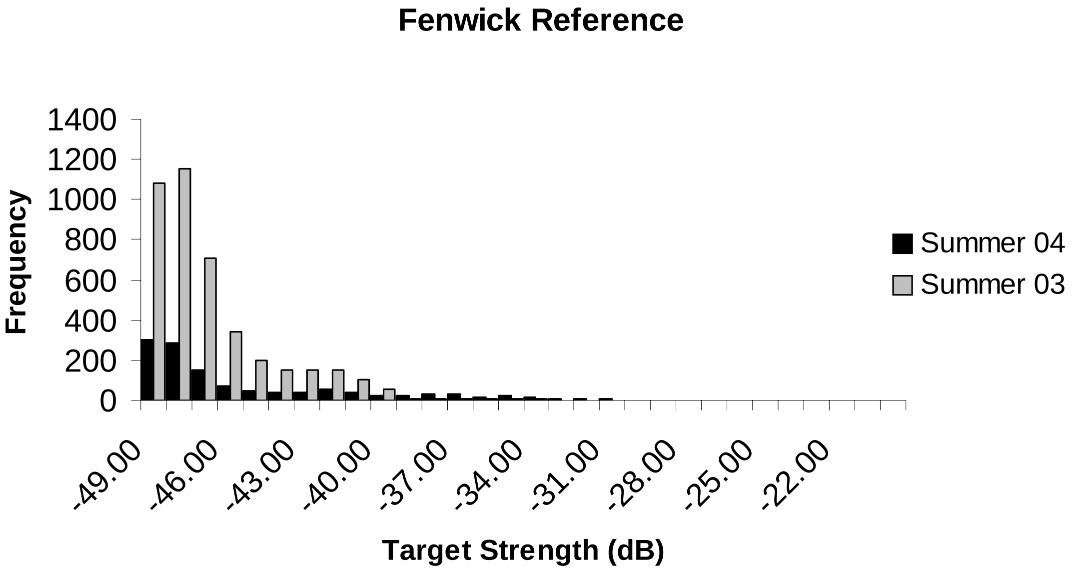
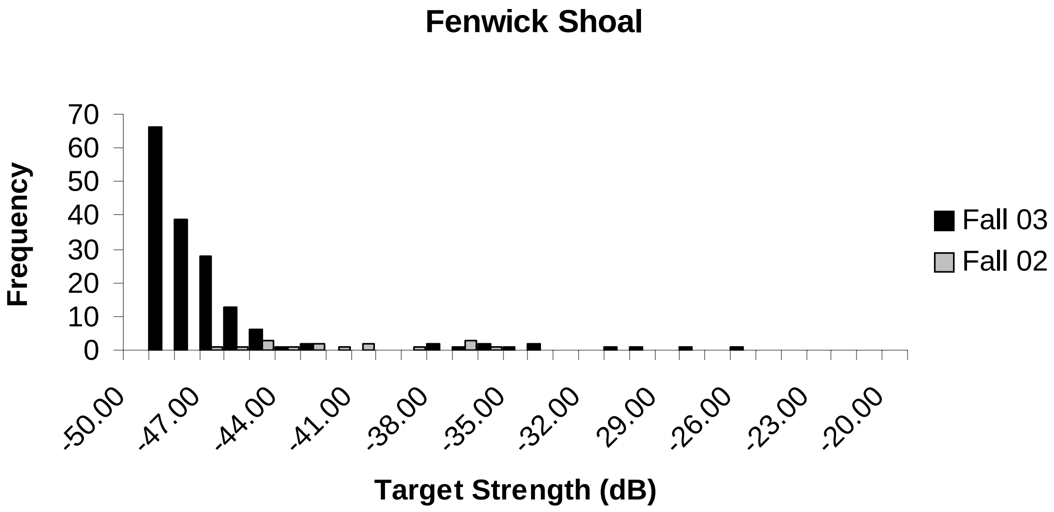


Figure 4-17. Seasonal size frequency distribution of fish satisfying individual target criteria from hydroacoustic transects (combined) during summer 03 and summer 04 sampling at Fenwick Shoal site and its reference area. Fish sizes are in decibels as measured with the acoustics. Using Love's (1977) equation, these target strengths equate roughly to the following: -50 dB is 35.0 mm; -45 dB is 63.9 mm; -40 dB is 116.8 mm; -35 dB is 213.4 mm; -30 dB is 389.9 mm; -25 dB is 712.4 mm; and –20 dB is 1301.7 mm.



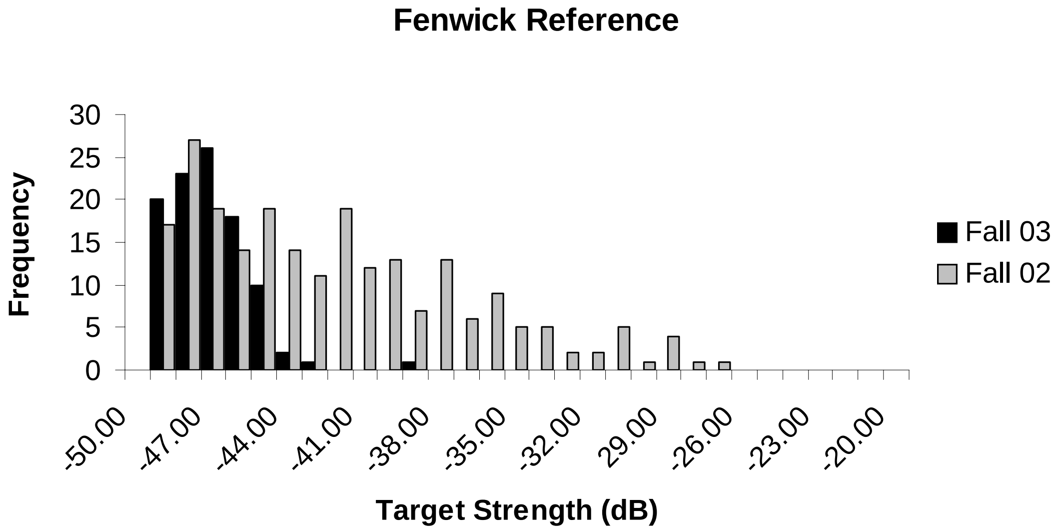
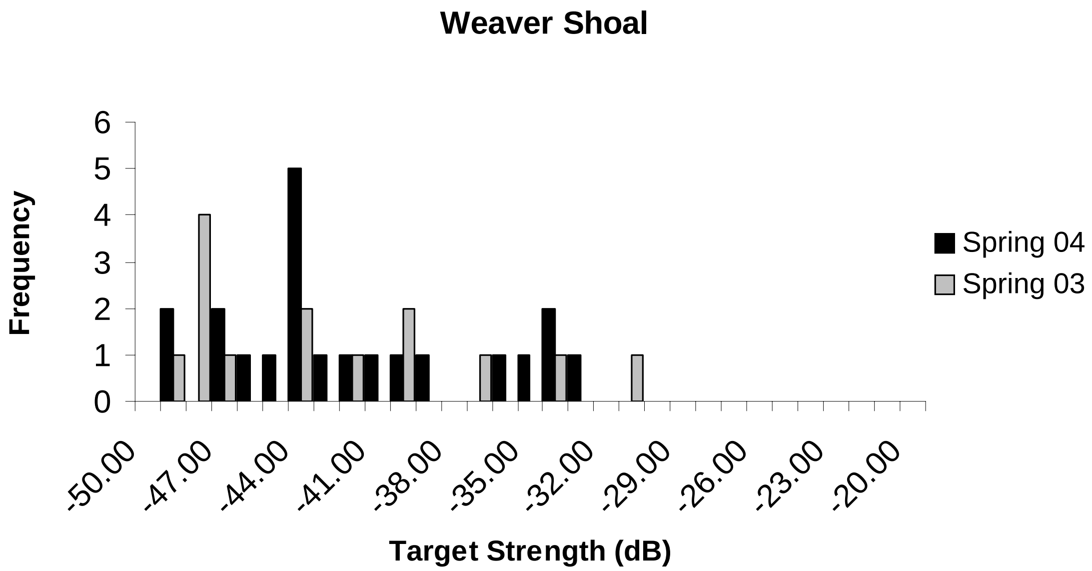


Figure 4-18. Seasonal size frequency distribution of fish satisfying individual target criteria from hydroacoustic transects (combined) during fall 02 and fall 03 sampling at Fenwick site and its reference area. Fish sizes are in decibels as measured with the acoustics. Using Love's (1977) equation, these target strengths equate roughly to the following: -50 dB is 35.0 mm; -45 dB is 63.9 mm; -40 dB is 116.8 mm; -35 dB is 213.4 mm; -30 dB is 389.9 mm; -25 dB is 712.4 mm; and –20 dB is 1301.7 mm.



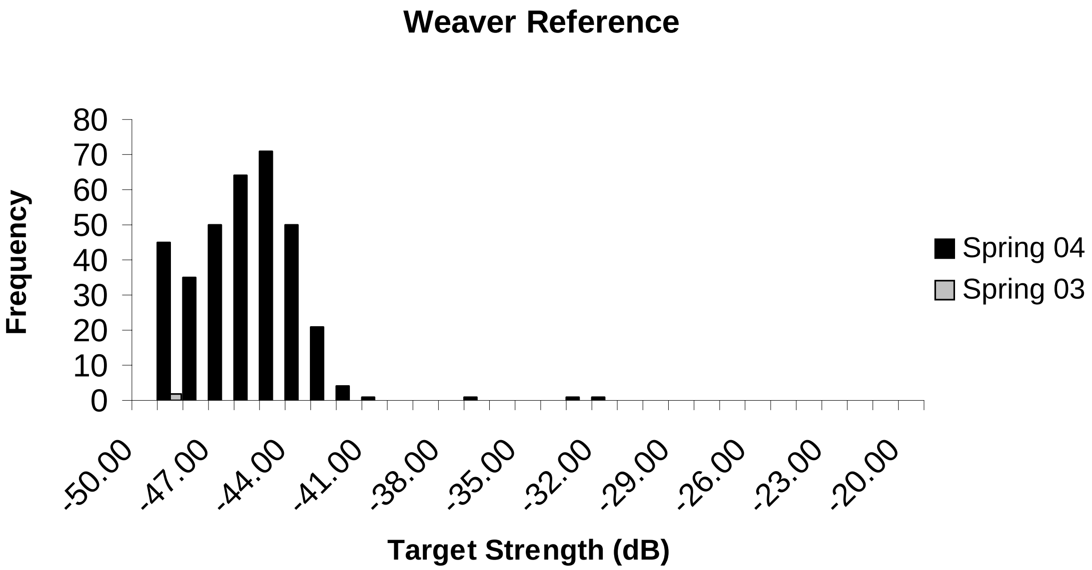
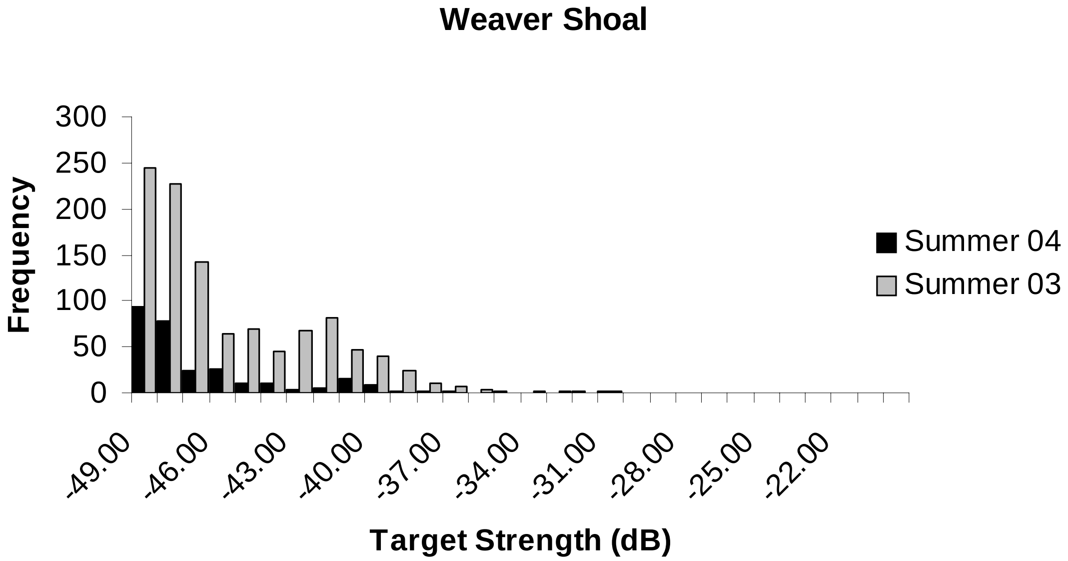


Figure 4-19. Seasonal size frequency distribution of fish satisfying individual target criteria from hydroacoustic transects (combined) during spring 03 and spring 04 sampling at Weaver Shoal site and its reference area. Fish sizes are in decibels as measured with the acoustics. Using Love’s (1977) equation, these target strengths equate roughly to the following: -50 dB is 35.0 mm; -45 dB is 63.9 mm; -40 dB is 116.8 mm; -35 dB is 213.4 mm; -30 dB is 389.9 mm; -25 dB is 712.4 mm; and –20 dB is 1301.7 mm.



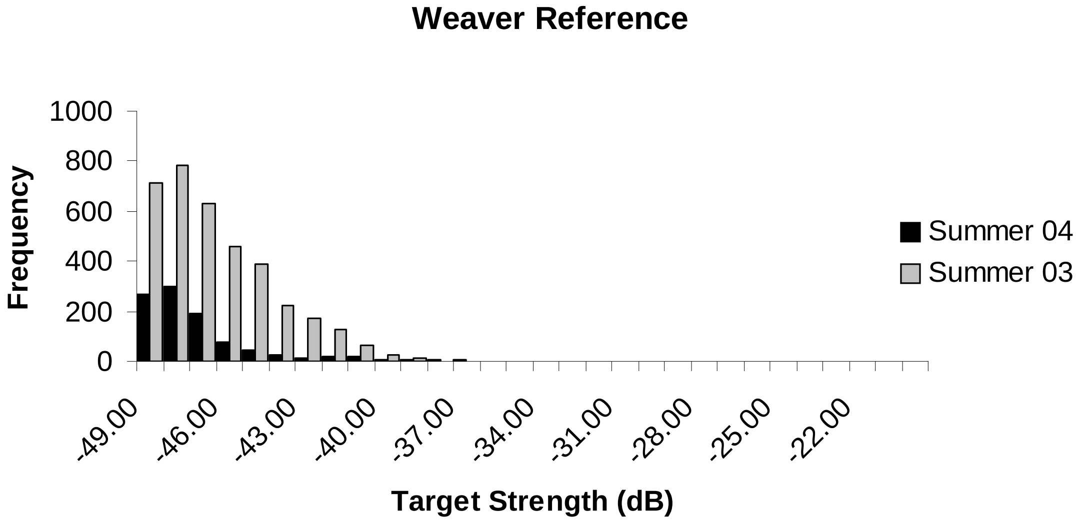
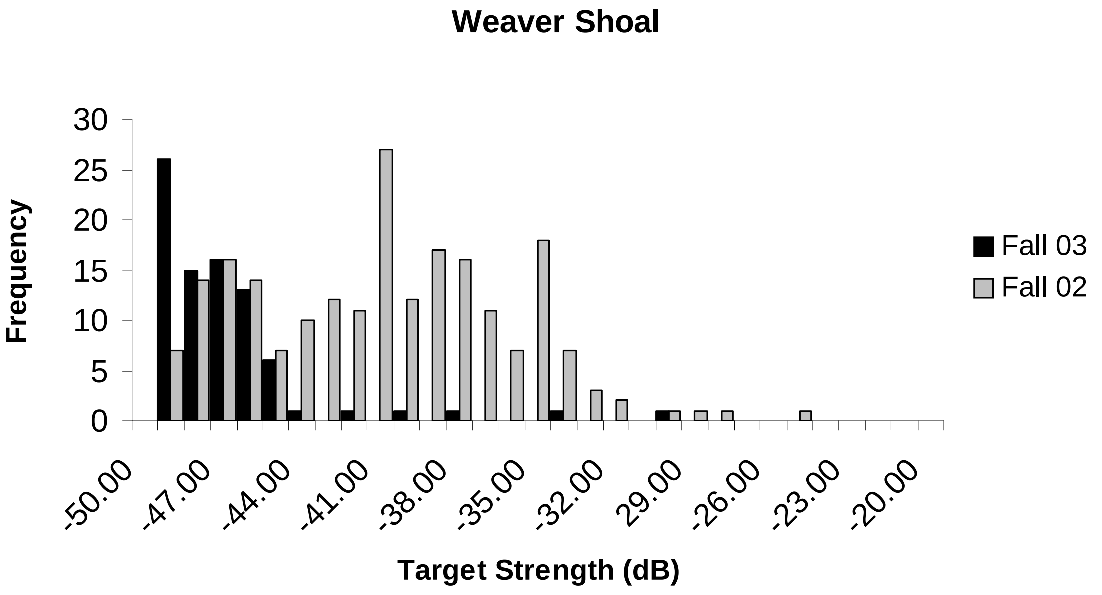


Figure 4-20. Seasonal size frequency distribution of fish satisfying individual target criteria from hydroacoustic transects (combined) during summer 02 and summer03 sampling at Weaver site and its reference area. Fish sizes are in decibels as measured with the acoustics. Using Love’s (1977) equation, these target strengths equate roughly to the following: -50 dB is 35.0 mm; -45 dB is 63.9 mm; -40 dB is 116.8 mm; -35 dB is 213.4 mm; -30 dB is 389.9 mm; -25 dB is 712.4 mm; and –20 dB is 1301.7 mm.



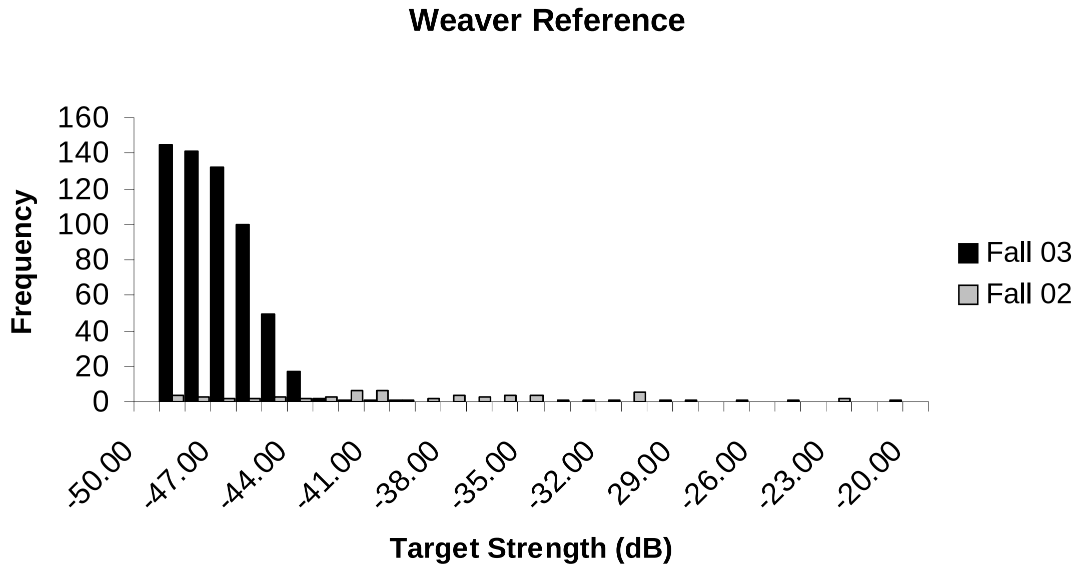


Figure 4-21. Seasonal size frequency distribution of fish satisfying individual target criteria from hydroacoustic transects (combined) during fall 02 and fall 03 sampling at Weaver site and its reference area. Fish sizes are in decibels as measured with the acoustics. Using Love's (1977) equation, these target strengths equate roughly to the following: -50 dB is 35.0 mm; -45 dB is 63.9 mm; -40 dB is 116.8 mm; -35 dB is 213.4 mm; -30 dB is 389.9 mm; -25 dB is 712.4 mm; and –20 dB is 1301.7 mm.

5.0 MANAGED SPECIES

Under the 1996 amendments to the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) all federal agencies that fund, permit, or undertake activities that may adversely affect EFH are required to consult with the National Marine Fisheries Service (NMFS). The EFH guidelines encourage using existing interagency consultation procedures or environmental reviews that notify NMFS with an assessment of the effects of proposed actions on EFH, and no appropriate procedures exist, then the consultation process outlined in 50 CFR 600.920 should be used. The lead Federal agency determines the effects of the proposed action on EFH, and if the action may have an adverse effect, then an EFH Assessment must be provided to the NMFS. Under the guidelines an adverse effect is “any impact that reduces quality and/or quantity of EFH, including direct (e.g. contamination and physical disruption), indirect (e.g. loss of prey, reduction in species’ fecundity), site-specific or habitat wide impacts, including individual, cumulative, or synergistic consequences of actions”. The length of the EFH Assessment can vary depending on the magnitude of the potential impacts to EFH (NMFS 2004).

EFH has been identified for a total of 59 species covered by 14 fishery management plans (FMPs), under the jurisdiction of the New England Fishery Management Council, Mid-Atlantic Fishery Management Council, or the NMFS. EFH designated for federally managed species is primarily based on the geographic distribution of species densities inferred from survey data gathered over the last 40 years (Reid 1999). If the data is available, separate EFH designations are given for the four life-history stages of each species (i.e., eggs, larvae, juveniles, and adults). For juvenile and adult life stages of fish and mobile invertebrate species (squid), EFH designations are developed from trawl data averaged within 10-minute squares (of latitude and longitude) and mapped over the continental shelf. In general, four alternative EFH designations are calculated from the species distribution defined by these squares. They are the 100, 90, 75, and 50% of the total abundance over all years of the trawl surveys. For most species the 75% or 90% distribution alternative is used as the definition of EFH (Reid 1999).

The NMFS has designated the area where this study occurred as EFH for a total of 25 fish and two invertebrate species (Table 5-1, NMFS web site 2006). From that group, a total of eleven fish and squid species were collected in this study. Several other fish species under management were also collected during the study and a comprehensive list of all the species under management collected in this study is presented in Table 5-2. Species with EFH designations collected in this study are highlighted. In addition, because we sampled with several nets of varying mesh sizes and species selectivity, Table 5-2 also indicates if juveniles or adult life stages were collected for species susceptible to multiple gears during those life stages.

Most of the species under management were collected infrequently and in limited abundance. Except for possibly scup, winter skate, and squids, a limited review of the data does not indicate consistently higher or lower numbers of species under management at the shoals or reference sites. Most of the managed species were migratory species collected during seasonal migrations through the study area. Migratory species included six alosids, Atlantic and Spanish mackerel, three Sciaenid species, butterfish, striped bass, bluefish, cobia, and six shark species. Among the sharks, spiny dogfish was the only species collected in high numbers throughout the duration of the study.

Several bottom dwelling demersal species, including red and silver hake, monkfish, black sea bass, scup and Atlantic cod were also collected in limited numbers during the study. Three flounder species were collected during the study, from which the windowpane was the most abundant. Some of the most abundant species collected in the study were skates. Overall, four skates were collected and from those the winter and little skate exhibited the highest abundance.

In addition to fish, the horseshoe crab and squid were collected at the sites. Horseshoe crabs were collected throughout the study in limited number. Although squid were not identified to species level while in the field, most of the squid collected in the study were likely short and long-finned squid, of which both have management plans.

Table 5-1. List of fish and invertebrate species by life-stage for which the study area in the Atlantic Ocean off the coast of Maryland and Delaware has been designated as Essential Fish Habitat by the National Marine Fisheries Service.

Taxonomic Name	Common Name	Eggs	Larvae	Juveniles	Adults
Clupea harengus harengus	Atlantic herring			X	X
Centropristus striata	Black sea bass		X	X	X
Thunnus thynnus	Bluefin tuna			X	X
Pomatomus saltatrix	Bluefish		X	X	X
Rachycentron canadum	Cobia	X	X	X	X
Scomberomorus cavalla	King mackerel	X	X	X	X
Lophius americanus	Monkfish	X	X		
Urophycis chuss	Red hake	X	X	X	
Stenotomus chrysops	Scup			X	X
Katsuwonus pelamis	Skipjack tuna				X
Scomberomorus maculatus	Spanish mackerel	X	X	X	X
Paralicthys dentatus	Summer flounder	X	X	X	X
Xiphias gladius	Swordfish			X	
Scopthalmus aquosus	Windowpane flounder	X	X	X	X
Glyptocephalus cynoglossus	Witch flounder	X	X		
Pleuronectes ferruginea	Yellowtail flounder		X		
Squatina dumerili	Atlantic angel shark		X	X	X
Rhizopriondon terraenovae	Atlantic sharpnose shark				X
Prionace glauca	Blue shark				X
Charcharinus obscurus	Dusky shark		X		
Odontaspis taurus	Sand tiger shark		X		X
Charcharinus plumbeus	Sandbar shark		X	X	X
Sphyrna lewini	Scalloped hammerhead shark			X	
Isurus oxyrhyncus	Shortfin mako shark		X	X	
Galeocerdo cuvieri	Tiger shark		X	X	
Loligo pealei	Long finned squid			X	
Spisula solidissima	Surf clam			X	X

Table 5-2. A list of fish species with management plans collected at four shoals and four reference sites in the Atlantic Ocean off the coast of Maryland and Delaware from November 2002 to September 2004. The study area is designated as EFH for highlighted species.

Taxonomic Name	**Common Name**	**Juvenile**	**Adult**
Alosa pseudoharengus	Alewife		X
Alosa sapidissima	American shad		X
Squatina dumeril	Atlantic angel shark		X
Gadus morhua	Atlantic cod		X
Micropogonias undulatus	Atlantic croaker	X	X
Clupea harengus harengus	Atlantic herring		X
Scomber scombrus	Atlantic mackerel	X	
Brevoortia tyrannus	Atlantic menhaden		X
Rhizoprionodon terraenovae	Atlantic sharpnose shark		X
Raja laevis	Barndoor skate	X	
Centropristis striata	Black sea bass	X	X
Alosa aestivalis	Blueback herring		X
Pomatomus saltatrix	Bluefish		X
Peprilus triacanthus	Butterfish	X	X
Raja eglanteria	Clearnose skate	X	
Rachycentron canadum	Cobia		X
Carcharhinus obscurus	Dusky shark	X	
Lophius americanus	Monkfish		X
Alosa mediocris	Hickory shad	X	
Limulus polyphemus	Horseshoe crab	X	
Raja erinacea	Little skate	X	
Urophycis chuss	Red hake	X	
Carcharhinus plumbeus	Sandbar shark	X	
Stenotomus chrysops	Scup	X	X
Merluccius bilinearis	Silver hake	X	
Scomberomorus maculatus	Spanish mackerel		X
Squalus acanthias	Spiny dogfish		X
Leiostomus xanthurus	Spot		X
Cephalopoda	Squids	X	X
Morone saxatilis	Striped bass		X
Paralichthys dentatus	Summer flounder		X
Alopias vulpinus	Thresher shark	X	X
Cynoscion regalis	Weakfish	X	X
Scophthalmus aquosus	Windowpane		X
Pleuronectes americanus	Winter flounder		X
Raja ocellata	Winter skate		X

6.0 DISCUSSION

Previous studies of habitat relationships have focused on macro and micro-scale habitat features (Diaz et al. 2003) or species-specific life stages within a particular habitat of the MAB (Able and Fahay 1998; Slacum 2005), but studies linking marine biota to large natural physical features, such as sand shoals, are rare. In the present study, we compared differences in species abundance, species richness, species diversity and community guild abundances between sand shoals and nearby uniform-bottom habitats on the inner-continental shelf of the MAB.

In general, the species collected at both habitats were comparable to those reported in other studies within the MAB (Musick et al. 1986; Diaz et al. 2003; Wirth 2001; Slacum 2005). There were extreme seasonal fluctuations in species distributions and abundance similar to those described in previous work (Colvocoresses and Musick 1984), with the highest diversity in the late summer and fall and the lowest in the winter. The multivariate cluster analysis conducted on the CPUE of all species shows a distinct difference in community composition between seasons, regardless of habitat (Figure 3-14). This is primarily due to the fact that the study area has one of the most extreme seasonal temperature ranges in the world, and the majority of the species collected in this study were highly migratory boreal or warm-temperate/subtropical species (Musick et al. 1986). Because of this, only a small percentage of the species encountered, 5 fish out of 57 and 2 invertebrates out of 17, were present or resident throughout all the seasonal surveys.

In addition to seasonal differences, there were also differences in all catches between years. These differences were not site specific and occurred throughout the sites in every season. More than likely these differences were due to annual changes in recruitment (population fluctuations) of certain species and the timing when seasonal surveys occurred between years. In general, the species collected in a particular season during year one were similar to those present in the same seasonal samples of the following year, and it was only the abundances of those species that varied. For example, the first fall commercial trawl sample had similar species composition as the second year fall sample (Table C-15). For the most part the species composition did not vary between years.

Based upon the net and bioacoustic surveys we determined there were distinct patterns in species abundances, species richness, species diversity and community guild abundance between the shoals and the reference sites. However, because each gear sampled a different portion of the species assemblages within each habitat (i.e., bioacoustics sampled fish with swim bladders at night), the patterns associated with each gear are somewhat different. The species distributions collected in the trawls indicates that the reference habitat is preferred over shoal habitat in the MAB. In fact, total species richness and total diversity values collected from commercial trawls were higher during every season at almost all the reference sites. Those same data also show no differences in mobile benthos between either habitat. In addition, gillnet data shows equal numbers of fish invertebrates at both habitats, suggesting that shoal habitat is not preferred over the reference site habitat for those species.

The analysis of the four faunal marine guilds found a similar trend in that shoals are not preferred over the reference site habitat. Both commercial and small trawls collected significantly higher abundances of benthic and pelagic fish species guilds at the reference sites, and there were no differences found between habitats in the gillnet data. These patterns were also shown in the multivariate analysis, which indicates differences in species composition between shoals and reference sites. These differences were due to several species in high abundance during seasonal samples. Species such a windowpane, butterfish, squid, and spotted hake were caught throughout seasonal samples and were consistently higher in abundance at the reference sites adding significantly to the abundance of both the benthic and pelagic finfish groupings. The abundance of benthic invertebrate (epi-benthic) groups between the two habitats showed no differences, also suggesting that shoals are not preferred by benthic invertebrate species when compared to the reference site habitat.

The data from the net survey indicate that more species in higher abundances used the reference sites more so than the shoals. If this is the case and higher diversity and species richness are determinants of preferred habitat, then we would determine that fish, squid and mobile epi-benthos in the MAB, either have no preference or prefer the reference site habitat over the high relief sand shoals. Presumably fish would be using the reference habitats more than the shoals because there are more food resources available. The availability of food resources has been shown to influence fish distribution in many marine species (Rooker and Holt 1997). Jenkins and Hamer (2001) found that the distribution of King George whiting was influenced more by prey availability than the density of seagrasses. Prey abundance was also a significant component of age-0 winter flounder distribution models from studies conducted in a New Jersey estuary (Stoner 2001). A recent survey by Cutter and Diaz (2000) found uniform-bottom areas in the troughs next to Fenwick Island and Weaver shoal to be more biologically productive than areas on the crest of those shoals. Although the reference sites in our study were not as close to shoals as the deep areas sampled in the Cutter and Diaz (2000), the reference sites exhibited similar features and likely similar biological productivity. In this study, no diet or forage base information was collected, but if the uniform-bottom sites in this study were similar to those sampled in the Cutter and Diaz (2000) survey, then this could be why fish and squid prefer the reference sites over the shoals. However, information collected in the bioacoustic survey does not suggest that pelagic fish prefer the reference site habitats more that the shoals at night.

The bioacoustic survey showed the majority of the time there were generally higher biomass and fish densities at shoals, but when tests were performed the analysis was split. Significantly higher biomass and fish densities were found at Fenwick Island and Weaver Shoal, and biomass and density values were equal or significantly lower the majority of the time at shoal D and B when compared to their reference pairs. An overview of the net and bioacoustic data presents no evidence indicating that more species susceptible to bioacoustics (i.e., fish with swim bladders) were present at Fenwick or Weaver shoal. In addition, because trawls and bioacoustics were not collected concurrently there is no way of knowing what species were present during the night, and it is conceivable that there could be a different species assemblage at night. Therefore, the fact that there is a somewhat conflicting pattern between night and day suggests that fish may be exhibiting a diel pattern of use at the shoals. That is, species numbers and species densities are different at the shoals in the day compared to the night.

There is a wealth of information pertaining to fish behavior or movements between habitats throughout the diel cycle (Helfman 1993; Wootton 1990). Most species are only active during limited periods in the diel cycle and within certain fish assemblages there are groups that exhibit different diel activity patterns (Helfman 1978). Many fish are only active at night, because of prey availability or because of predator avoidance during the day (Helfman 1993). In their study of juvenile fishes present on Fenwick Island Shoal, Diaz et al. (2003) showed through cluster analysis that different species assemblages were present on the shoal between day and night. In fact, the presence of fish in some habitats on the shoal was four times higher at night than in the day. Diaz et al. (2003) concluded that the fish are indeed exhibiting a diel behavior, by balancing the proximity of complex habitat found nearer to the troughs to the simpler habitats on the majority of the shoal. By doing this, fish are allowed greater refuge from predation during the day and can exploit shoal habitats with increased resources at night with less of a risk of predation (Diaz et al. 2003). Although the research conducted by Diaz et al. (2003) focused on juveniles (which would likely not be detected by the bioacoustic gear), it is plausible that larger predatory fish preying upon those smaller individuals would exhibit the same behavioral pattern of using the shoals to feed at night. In this case the data suggest that during the diurnal period fish prefer the reference sites, and at night the pattern was somewhat changed, with less variation in abundance between the habitats, and higher overall fish abundance on Fenwick Island and Weaver Shoal.

The net survey data shows that fish preferred all four reference sites over the shoals, but the bioacoustics indicates only two shoals, Fenwick Island and Weaver, were preferred to the reference site habitat. One explanation for higher use at these two shoals could be the amount of relief exhibited by the shoals, because each of the four study shoals exhibits varying degrees of relief (Conkwright and Williams 1996; Conkwright et al. 2000). Weaver Shoal, which is the smallest shoal, also has one of the steepest slopes, and Shoal D is the deepest shoal and has the least extreme relief. Fenwick Island is more similar to Weaver in relief and has the steepest shoreward slope in the region (Swift and Field 1981). Shoal B is closer to shoal D with no extreme grading. The fact that Fenwick Island and Weaver Shoal exhibit some of the most extreme relief (i.e., large depth variation) between the study shoals could be why there are more fish at these shoals compared to shoal B and D.

Although no studies could be found comparing the use of high relief habitat between night and day, there is a wealth of information regarding vertical relief and fish distribution (Brock 1954; Sale 1991; Williams 1990; Rilov and Benayahu 2000), however, depending on the species, not all the information suggests that relief alone is a determinant of higher fish use within a habitat (Frank and Shackell 2001; Snyder 2001; Anderson et al. 2005; Gratwicke and Speight 2005). Many other variables in addition to high relief have been shown to influence species distributions. For example, in a study of large offshore banks on the continental shelf of eastern Canada, Frank and Shackell (2001) showed that when using just the top of the banks, which exhibited little depth variation, there was no correlation with species richness, but when the slopes of the banks were figured into their analysis, thereby increasing the heterogeneity of depths within a bank, the high variation associated with depth was an important determinant of species richness. Another study by Anderson et al. (2005) using long-term trawl and detailed bathymetric data found that juvenile haddock on the Eastern Scotian Shelf prefer habitats with more rugged surfaces at finer scales, indicating that preferred habitats may be more complex than areas that are not preferred. Both studies concluded that megascale relief associated with a shelf or bank is not as important as the variety of relief available at differing scales within those habitats. (Frank and Shackell 2001; Anderson et al. 2005).

As *a priori*, the reference sites in this study were chosen based on macro and microhabitat similarities exhibited between them and the shoals. This was done to account for as much habitat variation as possible between the shoals and the paired reference sites so that if differences were detected, those differences would likely be due to the megascale relief and not differences associated with other habitat variables. This did not take into account the varying degree on habitat complexities within the shoals, but only similarities between the shoals and their chosen reference sites. In their benthic characterization of the study area habitats, Nestlerode and Diaz (2003) point out that many of the shoals and reference site habitats were patchy over multiple scales. Although, that characterization only documented the frequency and type of habitats at the shoals and not the proportion of habitats, if Fenwick Island or Weaver Shoal exhibit more complex habitats, it is likely that fish would prefer them to shoal D or B, although this cannot be determined from the current analysis.

If fish are reacting to the larger megascale habitat complexity over the entire shoal, then the diversity of adjacent habitat may also be influencing the distribution of species as well. A recent study by Slacum (2005) conducted at several shoals and troughs within Maryland State waters, found that micro and macrohabitat features collected using underwater video techniques did not influence the distribution of adult summer flounder, rather, mesohabitat features such as shoals and trough bathymetry were possibly influencing distribution. That study concluded that mesohabitat features may be proxies for other features such as appropriate currents or the availability of prey items.

The availability and proximity of food resources to Fenwick Island and Weaver shoal could also be influencing the distribution of fish in this study. The comprehensive survey conducted by Cutter and Diaz (2000) characterized the benthic communities on Fenwick Island and Weaver shoal and deeper adjacent areas. That characterization indicated that the deeper uniform-bottom areas surrounding the two shoals, especially the trough between the two shoals, were more biologically active and productive than were the tops of the shoals. Cutter and Diaz (2000) indicate that the area of greatest bathymetric change between the shoals is also the area with the most habitat diversity. Those areas surrounding the shoals might hold significant fish resources during the day, and as suggested by Diaz et al. (2003), if fish are using the more protected deeper trough areas during the day, and exploiting the resources on the shoals at night, the proximity of this habitat to the shoals might be influencing the higher biomass and densities at these two shoals compared to shoals B and D. However, again, because no similar information on benthic productivity is known from shoal B or D this cannot be determined from the current analysis. Therefore, the pattern of higher fish use of the Fenwick Island and Weaver shoals at night is clear, but the exact mechanism behind the higher use remains unclear.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this study was to determine what species resided on shoals in the MAB, and to evaluate if the shoals represent important habitat for those species. To accomplish those objectives we sampled the shoals and reference sites using several nets and bioacoustics sampling techniques. Two consecutive years of fisheries monitoring in Federal waters off the coast of Maryland and Delaware documented that there are significant seasonal variations in species richness and abundances at the shoals and reference sites in this region of the MAB. There were also yearly variations in abundance, but overall the seasonal patterns of species assemblages are consistent and the majority of the species inhabiting the shoals and reference site habitats are seasonal residents. Comparisons between the net and bioacoustic data suggest that pelagic fish are using habitats differently between day and night. Multiple analyses were conducted on the data collected over the two years and from those analyses we conclude:

- Fish and squid occurring in the MAB either have no preference or prefer substrates at uniform-bottom types to sandy shoals during the day.

- Benthic invertebrates have no preferences for shoals over uniform-bottom types.

- There are diel (Day/Night) differences in the abundance of pelagic fish using the shoals and reference sites.

In addition, we found that only two of the shoals, Fenwick Island and Weaver Shoal, exhibited higher fish use at night. Although the pattern of higher fish use is clear, the mechanism behind this pattern is not. As pointed out in our discussion, fish could be using the adjacent uniform-bottom habitats areas during the day and move onto the shoals at night to exploit new habitat, in which case shoals would represent an important resource for fish at night. However, it is clear that not all the shoals are preferred by pelagic fish at night, which suggests that all shoals are not alike or there are other factors influencing higher fish use of Fenwick Island and Weaver shoals. Therefore, if these shoals are to be used as sand resources for future beach nourishment activities, we recommend using the precautionary approach as outlined by Auster (2001), which advocates minimizing impacts until more information can be gathered as to why Fenwick Island and Weaver shoal were preferred over shoal B and D at night.

There are several data gaps that need to be filled before a full evaluation of the shoal habitat can be completed. This would involve more data collection and the use of existing data sets to further refine comparisons between the shoals. To aid in the interpretation of the bioacoustic data, nighttime commercial trawling should be conducted over the same sites for one year (i.e., four seasons). Because trawl data was not collected concurrent with the bioacoustic data there is no way of knowing what species were actually using the shoals at night. It is reasonable to assume that there were fish present on the shoals and reference sites that were not ensonified by the acoustics either because they have no swim bladder or they do not move up into the water column at night. In this study only daytime net surveys were conducted, therefore we do not know whether significant day night differences in abundance and species composition occurs with fish or other bottom dwelling species that could not be quantified by the hydroacoustic equipment.

In addition, using existing data in conjunction with data from this study and other new data would enhance the further interpretation of the ecological value of the shoals. For example, benthic community data collected by Cutter and Diaz (2001) at Fenwick Island and Weaver shoals could be used to establish a trophic linkage between the shoals and the communities associated with them. However, this data is not available for shoal B and D and must be collected for a thorough evaluation to be completed. Food habits data from fish would also help with establishing trophic linkages between the shoals and associated species, but that data is currently missing as well. Data from the habitat characterization in this study and other relevant habitat data from Cutter and Diaz (2001) survey and Maryland Geologic Survey (2004) could be used to determine the overall habitat complexity associated with the shoals. This information would help to determine if differences in habitat complexity associated with individual shoals might be influencing species distributions.

Until a more thorough evaluation of the shoals can be done, the best way to minimize impacts to biological resources dependent on the shoals would be to conduct sandmining activities in a way that insures that the habitat diversity associated with the shoals remains intact to some extent. We agree with Diaz et al. (2004), who suggest avoiding total removal of surficial substrates in such a way that habitat patches are left behind. This is beneficial not only because it preserves habitat diversity on the shoals, but will also leave representative patches of established benthic species and facilitate recolonization by providing a local source of potential recruits. Facilitating rapid recolonization of a mined site by established community members would minimize alteration of community structure and function and reduce potential effects upon trophically dependent fishes (Diaz et al. 2004).

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